

*Ecological Evaluation of the CWPPRA  
Central and Eastern Terrebonne Basin  
Freshwater Delivery Project*

FINAL REPORT



Coastal Ecology Institute  
School of the Coast and Environment  
Louisiana State University  
Baton Rouge, Louisiana

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March 2002

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Prepared for

Coastal Restoration Division  
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and

The Coastal Wetlands Planning, Protection, and Restoration Act Task Force

by

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## **CHAPTER 1: INTRODUCTION**

### **Background**

The “Central and Eastern Terrebonne Basin Freshwater Delivery Project” is a proposed CWPPRA project sponsored by the USFWS. The intent of the proposed project is to utilize in the central and eastern Terrebonne Basin the presently “unutilized” surplus freshwater flowing from the Atchafalaya River eastward through the Intracoastal waterway (ICWW) into Barataria Basin. The surplus flow that is potentially available for restoration of wetlands in Terrebonne Basin is estimated at 2,000 to 4,000 feet per second (cfs) (USFWS Draft Project Development Plan).

The intent of the freshwater delivery project is to implement an ecosystem strategy developed as part of the Coast 2050 plan regarding the utilization of Atchafalaya River water to enhance central and eastern Terrebonne Basin marshes, where land loss rates have been high. The surplus freshwater available is not sufficient to distribute throughout the central and eastern basin, therefore decisions must be made as to its best allocation.

The objective of the work reported herein is to evaluate the ecological condition of the habitat types in the project area, the historic trends of habitat change, and the potential for habitat restoration through diversion of part of the fresh water from the ICWW into Eastern Terrebonne Basin.

This report describes the results of our evaluation of the present ecological condition of the habitat types in the project area and the historic trends that influenced the region. Chapters are included on the marsh habitat analysis, vegetation, hydrology, soil bulk properties, and accretion (from analysis of cores). Then, we present a summary of that work along with additional information that facilitates a comparison of the ecological condition of the study areas to “ideal marsh” conditions, in order to provide resource managers with a tool to assist in determining the best allocation of the ICWW water among the potential receiving basins.

### **Approach**

Our approach to evaluating the ecological condition and historic trends of change in the habitat types includes several actions focused on providing relevant information that could be

useful for comparisons between the Lake Boudreaux and Grand Bayou basins. A field survey of the vegetation and soil (marsh substrate) conditions provided information on the current vegetation types present in the study area and the characteristics of the marsh mat. Soil cores were analyzed for bulk soil properties and mat depth and strength. Additional cores provided material for determination of accretion rates. An analysis of existing hydrologic data provides information on water elevations and salinities in the areas. Historic trends were evaluated by accessing land loss and vegetation databases available, and by updating these with photo-interpretation and mapping of vegetation types using 1998 aerial photography.

We then approached the issue of providing coastal resources managers the information useful for development of a restoration strategy by assembling (to the extent possible from literature sources) a data table describing the critical environmental conditions (variables) of the "target" habitat with which to compare data describing present marsh conditions within the study area. This approach emphasizes the concept that the successful restoration of a habitat can best be accomplished when the critical environmental conditions (variables) of the desired habitat type are clearly quantified. This set of criteria then becomes the "target" toward which restoration points. Restoration, in this context, is the trajectory of change of the critical environmental variables from the existing data set to the target data set.

## **CHAPTER 2: HABITAT CHARACTERIZATION**

### **Introduction**

This chapter starts with an introduction to the two study areas—Lake Boudreaux and Grand Bayou—in the Terrebonne Basin, followed by an historical survey of the vegetative changes within the study areas from 1949 to 1998. The trends leading to the present state of these two areas are examined to provide information for recommendations for freshwater allocation based on anticipated beneficial changes to these habitats. Next follows a current habitat analysis of the study areas, focusing on two indicators of marsh degradation—percentage of water within a marsh area, and the configuration of water bodies within the land areas—along with a summary of vegetation in the areas. An overall comparison of the two study areas concludes the chapter.

### **Locations of Study Sites**

The Grand Bayou and Lake Boudreaux study areas are located in the Terrebonne Basin within the Mississippi River Delta Plain. The study area boundaries were determined to include the regions of anticipated flow influence if water from the ICWW were added to the upper portion of each study area. The areas were defined using basin boundaries, and followed ridges, levees, canal systems, and lakes. More details for each study area follow.

#### **Grand Bayou Study Area**

Figure 2.1 shows the Grand Bayou study area. Boundaries for the study area are drainage canals along the natural levee of Bayou Lafourche, Bayou Point au Chien to the southwest, then following a canal that cuts over to Catfish Lake in the south. Catfish Lake marked the southernmost boundary. The northern boundary is an old ridge system along Bayou Blue that obstructs the flow of water from the north.

#### **Lake Boudreaux Study Area**

The Lake Boudreaux study area is identified in Figure 2.2. Boundaries for the study area include drainage canals within the study area along the eastern edge of Bayou Grand Caillou and the western edge of Bayou Petit Caillou. St. Louis Canal marks the northern boundary. Lake

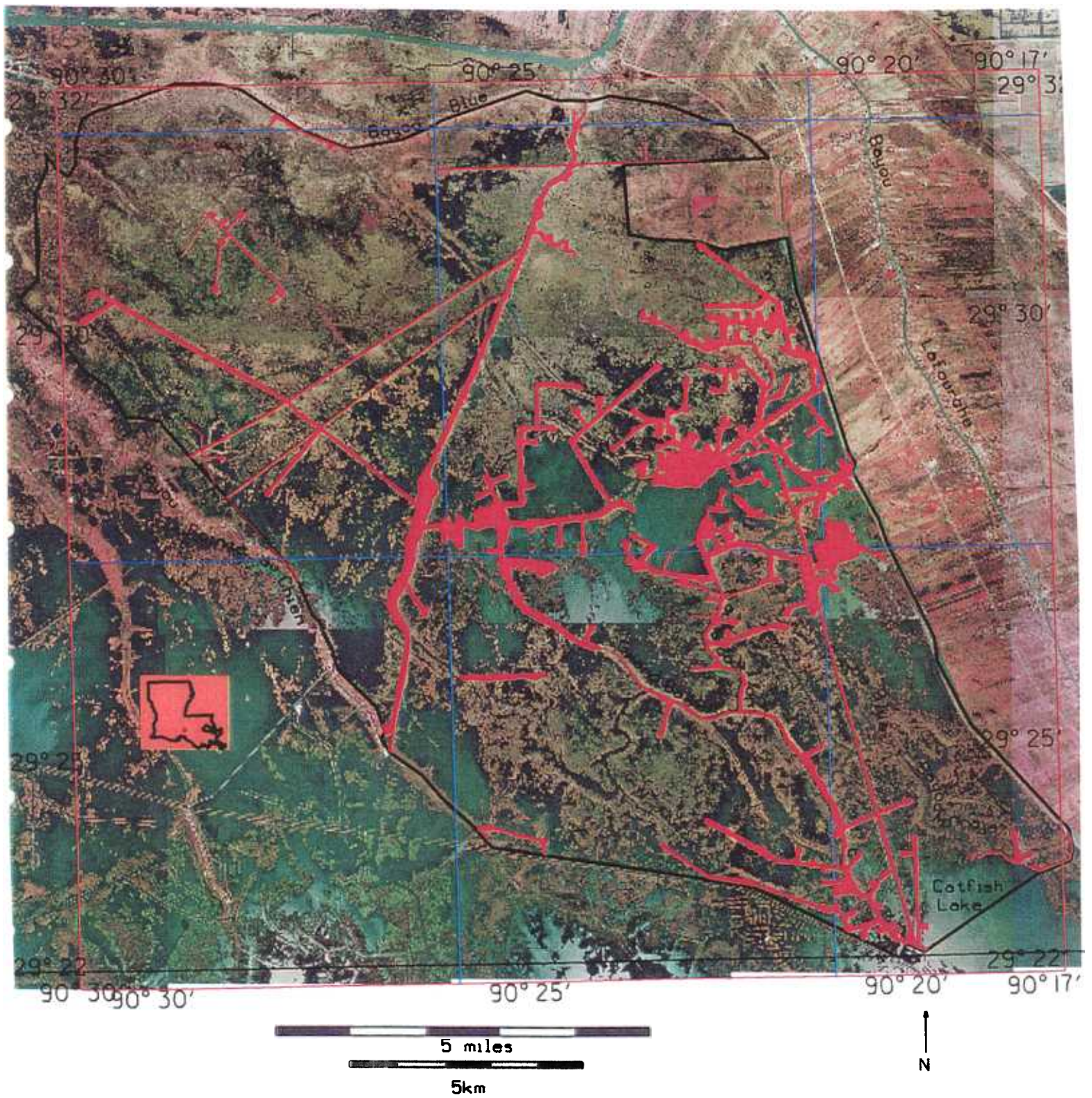


Figure 2.1. The Grand Bayou study area, with the canal system in red.

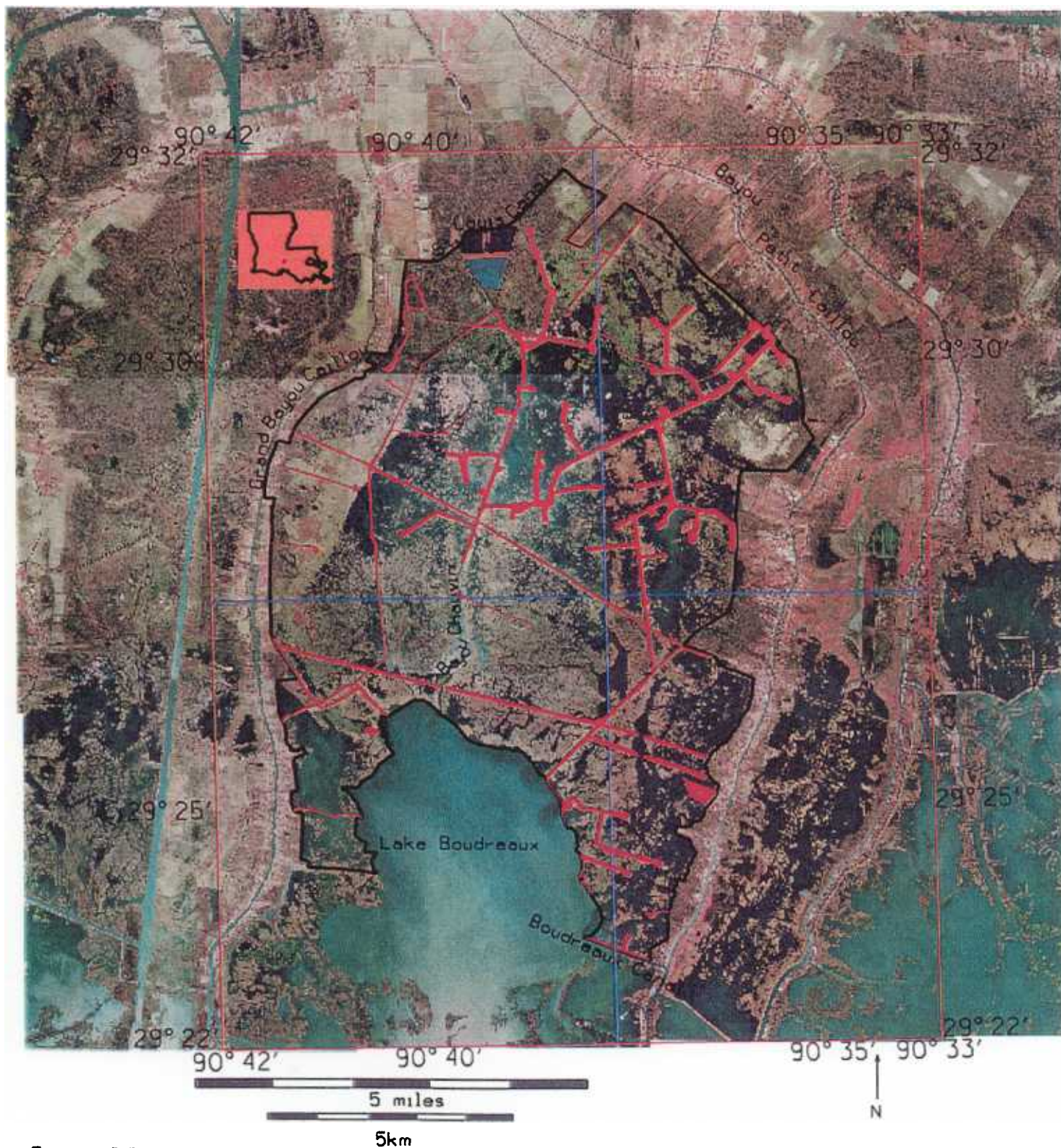


Figure 2.2 The Lake Boudreaux study area, with the canal system in red.

Boudreaux, Boudreaux Canal, and a canal connecting Grand Caillou to the lake determine the southern boundary. Bayou Chauvin flows from the north through the middle of the study area.

## **Methods**

### **Historical Data Comparison**

Data from O'Neil (1949) and Chabreck et al (1968, 1978, 1988, and 1998; figures 2.4a-e) were summarized by the United States Geological Service National Wetlands Research Center Coastal Restoration Field Station (NWRC) and the Louisiana Department of Natural Resources. Habitat analyses for 1956, 1978, and 1988-90, and the 1993 Land/Water analysis (figures 2.3a-e, NWRC 1956, 1978, 1990). These data, along with the addition of 1998 information from this study (figure 2.5), provide a historical perspective of habitat trends in the study areas over the last 50 years. Methods for these studies can be obtained from the references provided.

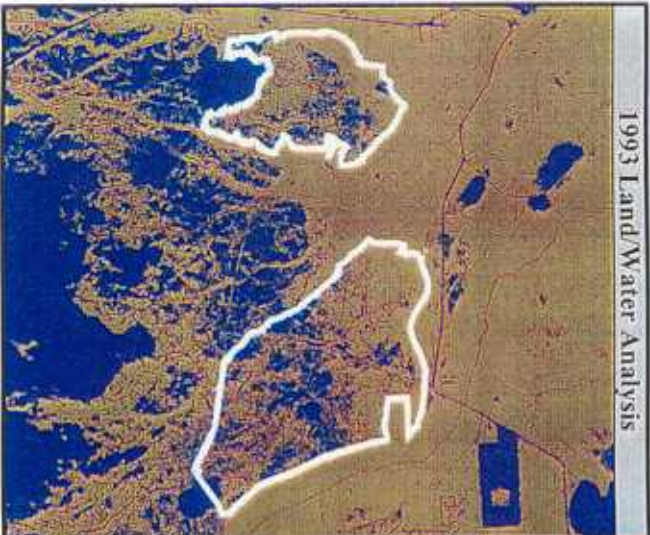
We updated the historical database in the study areas by photo interpreting 1998 aerial photography (see Habitat Analysis—1998 section). Different designations were used in the historical mappings and our 1998 comparison. Table 2.1 shows the summarized classification used for comparisons in this report, and their associated categories for the historical and updated data. To compare the two study areas, we used percentages of marsh area for each individual year. The marsh areas decreased as the years proceeded due to changes in the systems.

### **1988 Habitat Analysis**

#### *Photo-interpretation*

We interpreted digital orthophoto quarter quadrangle imagery flown in 1998 to determine the most recent vegetation characteristics for the study areas. This imagery was compressed using MrSID technology and geo-rectified through the Louisiana Oil Spill Coordinator's Office and made available on the Louisiana ATLAS website. We photo-interpreted directly into Intergraph Corporation's MGE (Modular Geographical Information System Environment), using a minimum mapping unit of 0.02 ha. We designated vegetation types based on species composition. Table 2.2 lists the vegetation classification categories that we identified, along with species included in each. We also characterized the land/water configuration as shown in Table 2.3 to determine the relative level of degradation of the marsh. This component used a

Figure 2.3. USFWS habitat analyses showing changes in the two basins from 1956 to 1990.

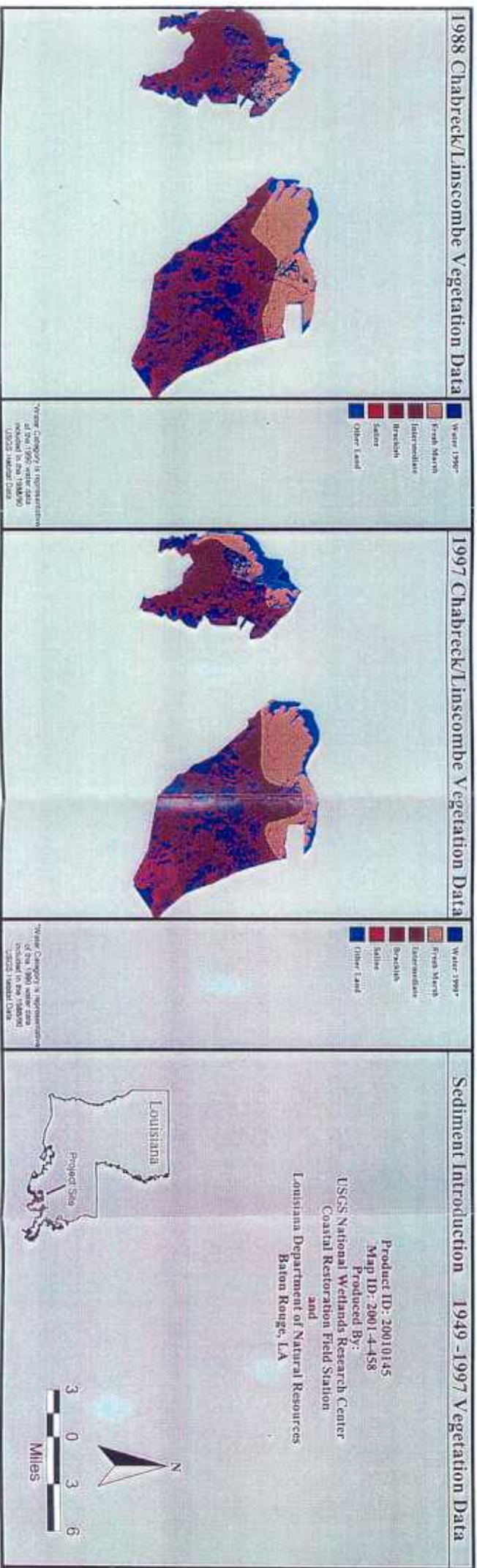
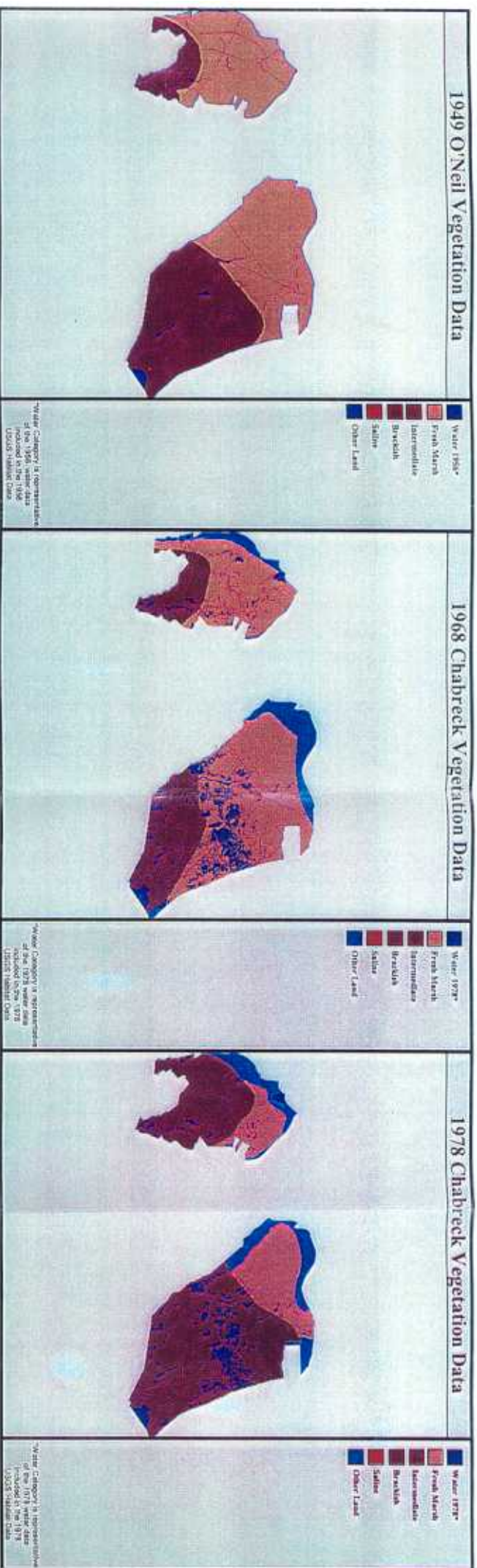


**Sediment Introduction Habitat Analysis**

Product ID: 20010145  
 Map ID: 2001-4-49  
 Produced By:  
 USGS National Wetlands Research Center  
 Coastal Restoration Field Station  
 and  
 Louisiana Department of Natural Resources  
 Baton Rouge, LA

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Figure 2.4. USFWS vegetation analyses showing changes in the two basins from 1949 to 1997.



# 1998 Analysis

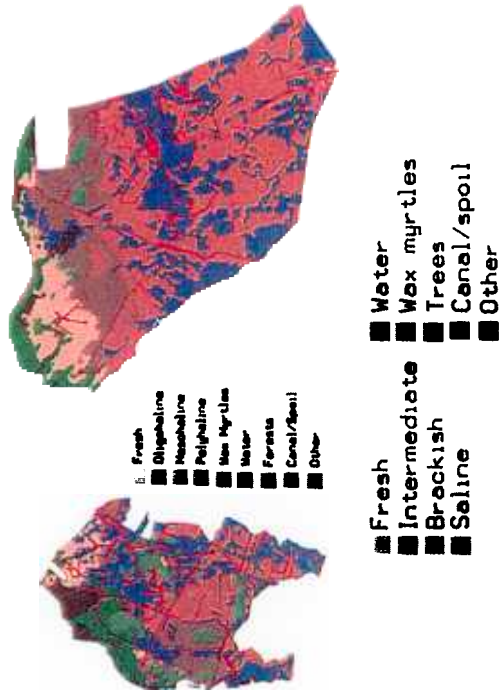


Figure 2.5. The 1988 habitat analysis for the Grand Bayou and Lake Boudreaux study areas.

Table 2.1. A listing of summarization categories used for comparisons over time, and their included categories from both the historical database and the updated 1998 data.

Class	Historical	1998
Fresh Marsh	Fresh	Fresh
Intermediate	Intermediate	Oligohaline
Brackish	Brackish	Mesohaline
Saline	Saline	Saline
Water	natural+artificial water bodies+shrub/scrub(spoil) +aquatic vegetation	water + canal/spoil+ category 6 (see page 13)
Forests	cypress+bottomland+upland+dead forests	Forests
Shrub/scrub	Upland and Bottomland Shrub/scrub, Wax myrtles, Canal spoil	Wax myrtles
Other	Ag/Pasture, Developed, Other land, No data available	Other

technique developed in earlier studies (Dozier et al 1983, Evers et al 1991) to classify the marsh into multiple categories based on estimates of percentages of marsh and water, and configurations of water bodies within the marsh, in order to provide indicators of the degree of marsh degradation. In previous studies we have included category 6, which represents 20-40% marsh in 60-80% water, in the water category. In the habitat analysis portion of the study, we retained category 6 as a separate marsh category because it represents vegetated area that had been severely impacted. We wanted to determine its occurrence in reference to open water and to other degrees of marsh degradation.

Our classification system employed two indicators. We used classes 1 through 6 to indicate the amount of water within a marsh. The configurations a, b, and c represent the size and shape of water within the marsh—as larger open water bodies, or as smaller pockets of water.

Table 2.2. Species composition of the vegetation types identified in the Grand Bayou and Lake Boudreaux study areas.

Abbr.	Vegetation Type	Species Present
FM	Fresh Maidencane	<i>Panicum hemitomon</i> (dominant) <i>Thelypteris palustris</i> , <i>Decodon verticillatus</i> , <i>Sagittaria lancifolia</i> , <i>Eleocharis parvula</i> , <i>Eleocharis</i> sp., <i>Leersia oryzoides</i> , <i>Triadenum virginicum</i> , <i>Hydrocotyle</i> sp., <i>Baccharis halimifolia</i> , <i>Kosteletzkya virginica</i> , <i>Ptilimnium capillaceum</i> , <i>Rhynchospora</i> sp., <i>Boehmeria cylindrica</i> , <i>Cyperus</i> sp., <i>Eupatorium capillifolium</i> , <i>Polygonum sagittatum</i> , <i>Rhynchospora</i> sp., <i>Solidago sempervirens</i>
FB	Fresh Bulltongue	<i>Sagittaria lancifolia</i> (dominant), <i>Amaranthus australis</i> , <i>Lythrum lineare</i> , <i>Echinochloa walteri</i> , <i>Scirpus validus</i> , <i>Leptochloa fascicularis</i> , <i>Polygonum punctatum</i> , <i>Eleocharis</i> sp., <i>Phyla lanceolata</i> , <i>Eupatorium capillifolium</i> , <i>Echinochloa walteri</i> , <i>Lythrum lineare</i> , <i>Hydrocotyle</i> sp., <i>Solidago sempervirens</i> , <i>Paspalum vaginatum</i> , <i>Amaranthus australis</i>
FS	Fresh Spikerush	<i>Hydrocotyle</i> sp., <i>Bacopa monnieri</i> , <i>Eleocharis baldwinii</i> , <i>Scirpus americanus</i> , <i>Phyla lanceolata</i> , <i>Paspalum vaginatum</i> , <i>Ptilimnium capillaceum</i> , <i>Setaria geniculata</i> , <i>Solidago sempervirens</i>
OB	Oligohaline Bulltongue	<i>Sagittaria lancifolia</i> (dominant), <i>Paspalum vaginatum</i> , <i>Amaranthus australis</i> , <i>Lythrum lineare</i> , <i>Eleocharis</i> sp., <i>Bacopa monnieri</i> , <i>Spartina patens</i> , <i>Leptochloa fascicularis</i> , <i>Eleocharis cellulosa</i>
OPT	Oligohaline Paspalum Transition	<i>Paspalum vaginatum</i> (dominant), <i>Amaranthus australis</i> , <i>Distichlis spicata</i> , <i>Scirpus americanus</i> , <i>Sagittaria lancifolia</i> , <i>Kosteletzkya virginica</i> , <i>Echinochloa walteri</i> , <i>Ptilimnium capillaceum</i> , <i>Scirpus validus</i> , <i>Cyperus</i> sp., <i>Bacopa monnieri</i>
OW	Oligohaline Wiregrass	<i>Spartina patens</i> (dominant), <i>Iva frutescens</i> , <i>Pluchea camphorata</i> , <i>Lythrum lineare</i> , <i>Typha</i> sp., <i>Kosteletzkya virginica</i> , <i>Amaranthus australis</i> , <i>Lythrum lineare</i> , <i>Ptilimnium capillaceum</i>
MM	Mesohaline Mixture	<i>Spartina alterniflora</i> , (dominant) and/or <i>Distichlis spicata</i> (codominant), <i>Spartina patens</i> (codominant), <i>Aster tenuifolius</i>
MW	Mesohaline Wiregrass	<i>Spartina patens</i> (dominant), <i>Distichlis spicata</i> , <i>Spartina alterniflora</i> , <i>Paspalum vaginatum</i> , <i>Scirpus americanus</i>
P	Polyhaline	Polyhaline oystergrass (dominated by <i>Spartina alterniflora</i> ), or <i>Baccharis halimifolia</i> (dominant), <i>S. alterniflora</i> , <i>S. patens</i>

Table 2.3. Classification system used for photo-interpreting the 1998 imagery.

Classification	Percentage water
1	<5% water
2abc*	5%-10%
3abc	10%-25%
4abc	25%-40%
5abc	40%-60%
6	60%-80%
Water	80%-100% water, including natural waterways
Canal/Spoil	canals plus their spoil area
Wax Myrtles	
Trees	swamps, upland forests
Other	other non-marsh areas

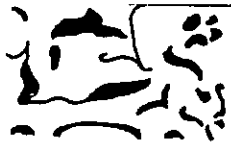
\*a These marshes have larger individual, randomly spaced water bodies with identifiable shorelines separated by solid marsh.

b These marshes have a matrix of small, regularly spaced water bodies.

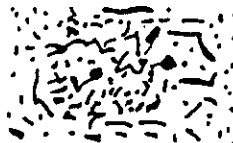
c These marshes have a combination of "a" and b, consisting of "a" matrix of small, regularly-spaced water bodies within areas of larger, randomly-spaced water bodies.

Examples of configurations:

4a.



4b.



4c.



### *Field Verification*

Prior to photo-interpretation, reconnaissance trips by boat were made to both of the study sites to establish a framework for vegetative classification and land configuration to identify general photographic signatures. Information obtained by LSU and USFWS personnel on several other field examinations by boat, helicopter, and airboat insured accuracy in the mapping process.

## Results

### Historical Data Comparison

#### *Grand Bayou Study Area*

Natural streams in the study area were located mostly in the southeastern half of the region of the Grand Bayou study area in 1956. These included Grand Bayou, Bayou Monnaje, Bayou Blue, and Bayou Bouillon. Locations of these bayous are shown in figure 2.1.

Table 2.4 summarizes the USFWS Habitat Analysis data for the Grand Bayou study area, along with the updated 1998 data. Table 2.5 summarizes the study area landscape, along with the chronology of the changes that occurred, as presented in figures 2.1 and 2.3a-e, 2.4a-e and 2.5.

Figure 2.4a shows O'Neil's (1949) map as summarized by NWRC for comparison with the habitat maps. O'Neil mapped the vegetation of the study area as Fresh Floating (maidencane) marsh in the northern half of the area, with Floating Three-cornered Grass marsh in the southern half. These categories were summarized as fresh and brackish marshes, respectively, for 1949 in figure 2.4a. We think that this Floating Three-cornered Grass marsh probably represented a low salinity (intermediate) marsh, rather than brackish marsh. The 1956 Habitat Analysis, using O'Neil's vegetation classes to delineate fresh and nonfresh (figures 2.3a and 2.4a), identified the study area as fresh, but it also included the low salinity marshes.

Table 2.4. Areas of habitat by category for the Grand Bayou study area, as determined by USFWS and this study.

Class	1956		1978		1988-90		1998	
	Ac	ha	Ac	ha	Ac	ha	Ac	ha
Water	2757.1	1115.8	12267.1	4585.1	21504	8621.6	21190.1	8575.3
Marsh	49285.8	19945.3	38944.6	15760.3	30883.4	12498.1	31504.2	12749.3
<i>Fresh Marsh</i>	49285.8	19945.3	9889.5	4002.1	9985.1	4004.8	4478.5	1812.4
<i>Non-Fresh Marsh</i>	0		NU		NU		NU	
<i>Intermediate Marsh</i>	NU		11723.9	4744.5	7051.6	2853.7	7621.5	3084.3
<i>Brackish Marsh</i>	NU		17226.6	6971.4	13779.7	5576.4	19038.0	7704.4
<i>Saline Marsh</i>	NU		104.6	42.3	67.0	27.1	366.1	148.2
Forest	4327.9	1751.4	3683.7	1577.3	2961.1	1850.1	3259.4	1319.0
Shrub/Scrub	637.7	258.1	2087.1	844.6	1542.4	624.2	499.7	202.2
Other	383.0	155.0	408.9	165.4	501.7	203.0	939.3	380.1
Total	57391.5	23225.4	57391.4	23225.4	57392.6	23225.9	57392.4	23225.9

Table 2.5. Chronology of landscape conditions and changes in the Grand Bayou study area over the period 1949 to 1998.

1949	<p>O'Neil (1949) identified northern portion of the study area as Floating Fresh marsh, dominated by canouche (<i>Panicum hemitomon</i>), and the southern portion as Floating Three-cornered Grass marsh.</p> <p>Because this is not a detailed land/water map, no determination of marsh condition was made.</p>
1956	<p>The marsh was intact throughout the study area.</p> <p>The 49286 ac of marsh within the study area was mapped as fresh, but also included the low salinity marshes. (Note: The mapping categories in 1956 were fresh/nonfresh.)</p> <p>Several canals, along with associated spoil areas (included in the shrub/scrub category) were present in the middle of the study area.</p> <p>A forested area—probably a mixture of upland/bottomland/dead—was located along northern study area border.</p>
1968	<p>Chabreck, Joanen &amp; Palmisano (1968) identified the area as mostly fresh (approximately 75%), with a band of brackish marsh along the southern border of the study area, with a smaller band of intermediate marsh sandwiched between the fresh and intermediate.</p>
1956-1978	<p>The major marsh deterioration that occurred in the middle of the study area is contrasted with the intact area of fresh marsh to the northwest. The northeastern section of the fresh marsh contained an area of open water. The southern portion of the brackish marsh had deteriorated somewhat.</p> <p>Overall, marsh area decreased by approximately 10350 ac. Fresh/Intermediate marsh area was reduced by 27672.4 ac between 1956 and 1978. Brackish marsh within the study area covered 13780 ac in the study area by 1978, with the 105 ac of saline marsh just inside of the southern border.</p> <p>The water category increased 1828 ac by 1978. New, large areas of open water were present in the 1978 intermediate/brackish interface area, especially on the eastern side of the study area.</p> <p>Shrub/scrub (spoil) increased, mostly associated with new canals along the intermediate/brackish border.</p>
1978-1988/90	<p>Within the brackish marsh, a large amount of marsh was lost both as large areas of open water and smaller ponding.</p> <p>Total marsh area decreased by 8061 ac, with intermediate marsh encroaching into fresh marsh, and brackish into intermediate. Still very little saline marsh in the study area.</p> <p>Between 1978 and 1988, open water area had increased by 4036 ac. The brackish marsh area (covering the lower portion of the study area) included large areas of open water, especially south of the area that opened up by 1978.</p> <p>Shrub/scrub areas (including some spoil banks) decreased, due to the increase of open water in the middle of the site.</p>
1993	<p>Visual observations showed that open water increased since 1990 in the fresh and intermediate areas. No summary numbers were available.</p>
1988/90-1998	<p>Fresh marsh decreased 2192 ac, while brackish marsh increased by 5258 ac. Intermediate and polyhaline marsh areas increased by 570 ac and 299 ac, respectively.</p> <p>Open water areas remained relatively constant, increasing by 314 ac.</p>
Summary	<p>The largest amount of landloss occurred between 1956 and 1988. During the 1956-1978 interval, large areas were lost in the middle of the study area at the intermediate/brackish border. The loss occurring between 1978 and 1988 was associated with enlarging of the open water areas already present, plus smaller ponding in the southern half of the study area.</p>

O'Neil's map was not intended to be a detailed vegetation community type map but rather to provide a general view of marsh habitats. It provided areas of general interest to natural resource managers at the time in regard to muskrat management, but left out some information on landscape features that are of interest to today's resource managers, including boundaries of vegetation types and locations and areas of canals, and other types of land. The 1956 habitat map also documented several canals already in place by this time.

All of the marsh in the study area was classified as fresh (that is, fresh/intermediate) in 1956. In an aerial survey of the Louisiana coastal marshes to determine large-scale marsh vegetation types, Chabreck, Joanen and Palmisano (1968) found most of the study area to still be fresh marsh, but with an encroachment with more salt-tolerant species in the southernmost portions of the study area. The 1978 Habitat Analysis determined land/water boundaries, and relied on Chabreck and Linscombe's 1978 Vegetation Type Map for delineation of fresh and non-fresh habitats. By 1978, all marsh types were represented within the study area. The fresh and intermediate types were reduced to 20% of the area they covered in 1956 (Table 2.5). Brackish marsh covered 44% of the study area, with the saline marsh accounting for a sliver of the marsh along the southernmost border of the study area.

Part of the decrease in the marsh area between 1956 and 1978 is due to a fourfold increase in water area during that time interval. Large open water areas were especially noticeable on the eastern side of the study area along the intermediate/brackish interface in 1978. No comparable large water areas emerged in the 1978 Lake Boudreaux intermediate/brackish interface. The canal network in the study area, along with the associated spoil banks, also increased over the time interval.

The Chabreck and Linscombe (1988) Vegetation Type Map, used for the brackish/intermediate and fresh/intermediate delineations of the land area mapped for the Habitat Analysis, showed an overall decrease in marsh area between 1978 and 1988 (Table 2.4). While the area of fresh marsh remained constant over the time period due to its encroachment into non-marsh areas, intermediate, brackish and saline marsh areas decreased. In 1988/90, the brackish marsh area, which covered the lower portion of the study area, included large areas of open water, especially south of areas that had opened up by 1978. The open water present in the middle of the site by 1990 "drowned" even some spoil banks.

In the 1993 Land/Water Analysis (figure 2.3d), open water had increased in the fresh and intermediate areas, but these areas were still not as open as the brackish area was by 1990. The areas of marsh and water did not change appreciably between 1988/90 and 1998. A tongue of brackish marsh along the western boundary encroached more northerly, and the intermediate marsh on the eastern side of the study area expanded westward by 1998 (figure 2.5).

#### *Lake Boudreaux Study Area*

Bayou Chauvin was the only natural stream in the study area in 1956, running from north to south (figures 2.1 and 2.3a). An east/west canal crossed the study area. Several north/south canals on the western side of the study area, and one in the southeast had already been dredged by 1956.

Table 2.6 summarizes the USFWS Habitat Analysis data in the Lake Boudreaux study area, along with the updated 1998 data. Table 2.7 describes the landscape, along with the changes that occurred between each time period, as presented in figures 2.1 and 2.3a-e.

Figure 2.4a shows O'Neil's (1949) map as summarized by NWRC for comparison with the habitat maps. O'Neil described the vegetation of the Lake Boudreaux study area as Fresh Floating (maidencane) marsh covering most of the area, with Floating Three-cornered Grass marsh around the periphery of Lake Boudreaux. Table 2.6 summarizes these marsh types as fresh and brackish. We think that this floating Three-cornered Grass marsh represented a low salinity marsh (fresh/intermediate) rather than brackish marsh.

As stated previously, the 1956 Habitat Analysis used O'Neil's vegetation classes to map the boundary between fresh and non-fresh (figures 2.3a and 2.4a). The Lake Boudreaux study area marshes were classified as fresh marsh, however the marsh types present included some low-salinity intermediate marsh as well. In 1968, Chabreck, Joanen, and Palmisano reported the introduction of brackish marsh into the area, along with the fresh/intermediate line being pushed slightly to the north (figure 2.4b). The 1978 Habitat Analysis relied on Chabreck and Linscombe's 1978 Vegetation Type Map for delineation of fresh and non-fresh habitats (figure 2.4c). Between 1956 and 1978 the overall marsh area decreased (Table 2.7). Most of the lower salinity marsh are in the eastern "leg" of the study area (comprising both fresh and intermediate marsh types in 1956) became brackish (figures 2.3a and b). By 1978, saline marsh was

Table 2.6. Chronology of the landscape and changes in the Lake Boudreaux study area over the period 1949 to 1998.

1949	O'Neil (1949) mapped most of the area as Floating Fresh marsh, dominated by canouche ( <i>Panicum hemitomon</i> ). A rim of Floating Three-cornered Grass marsh located in an arc is indicated around Lake Boudreaux.
1956	<p>The study area was mapped as fresh, however the category also includes the low salinity marshes. (Note: The mapping categories in 1956 were fresh/nonfresh.)</p> <p>Natural streams were located mostly in the southeastern half of the study area.</p> <p>Several canals were present in the middle of the study area.</p> <p>Swamps located along the northwestern edge of the study area, with other forested areas located along the western border, south of the swamp.</p> <p>No shrub/scrub.</p>
1968	Chabreck, Joanen, & Palmisano (1968) identified the study area as being mostly fresh, with an arc of brackish marsh on the northeastern side of Lake Boudreaux, and an arc of intermediate marsh above the brackish and also along the western edge of Lake Boudreaux.
1956-1978	<p>Overall, marsh area decreased. Fresh marsh area (comprising both fresh and intermediate marsh types) was reduced, becoming brackish marsh in the southern portion of the study area.</p> <p>Water area increased from 674 ac to 2793 ac. Areas of water were indicated along a north/south line near the eastern study area border, along with some larger water bodies that opened up in the marsh in the middle of the study area.</p> <p>Shrub/scrub was present, which were probably wax myrtles.</p>
1978-1988/90	<p>Marsh area decreased, but less than previously, in part due to an increase in marsh area due to the change from the category of "other land" (non-marsh land) to intermediate marsh. Intermediate marsh encroached into fresh marsh and "other land", as did brackish into intermediate. Still no saline marsh in the study area.</p> <p>In 1988/90, a large block of the 1978 fresh marsh/shrub/scrub became open water south of the 1978 intermediate/fresh line. Marsh along the eastern border of the study area also became open water.</p> <p>The area of shrub/scrub in 1978 mostly became open water by 1988/1990. Shrub/scrub category decreased, and locations of shrub/scrub now along the western edge of the study area.</p> <p>In 1978, no dead swamp was noted, but 52 ac of dead forest are included in the 1988 habitat map. A V-shaped area opened up in the swamp.</p>
1993	Open water area increased in the fresh and intermediate areas, and in the northern brackish areas.
1988/90-1998	<p>There was some encroachment of intermediate marsh into the fresh marsh, with the fresh marsh covering slightly less area, and intermediate marsh covering more than in 1990. The intermediate/brackish lines have shifted a little. In 1998 there was some intermediate marsh within the brackish marsh along water bodies.</p> <p>Wax myrtles are still present throughout the study area, in fresh to brackish marshes. By 2001, the southernmost wax myrtles had died, but were still standing.</p> <p>By 1998, the western "leg" of the study area had saline marsh. This was the first notice of saline marsh within the study area.</p>
Summary	Overall in the study area, the largest amount of marsh was lost between 1956 and 1988. The 1957-1978 loss occurred as large areas of aquatic vegetation along a SW-NE tangent through the study area. The loss between 1978 and 1988 was in the 1978 northern intermediate marsh that was included inside of the 1990 brackish marsh.

Table 2.7. Areas of habitat by category for the Lake Boudreaux study area, as determined by USFWS and this study.

Class	1956		1978		1988-90		1998	
	Ac	ha	Ac	ha	Ac	ha	Ac	ha
Water	673.5	272.6	4860.6	1130.1	8884.1	3500.0	9073.5	3671.9
Marsh	20893.5	8455.3	14431.1	5840.1	12150.0	4916.9	11419.5	4621.3
<i>Fresh Marsh</i>	20893.5	8455.3	4211.6	1704.4	1930.8	781.4	1636.3	662.2
<i>Non-Fresh Marsh</i>	0		NU		NU		NU	
<i>Intermediate Marsh</i>	NU		7980.1	3229.4	4109.5	1663.1	4167.4	2158.5
<i>Brackish Marsh</i>	NU		2239.4	906.3	6109.7	2472.5	5333.8	2158.5
<i>Saline Marsh</i>	NU		0	0	281.9	114.1		
Forest	4273.7	1729.5	3653.6	1478.6	2991.8	1210.8	2588.4	1047.5
Shrub/Scrub	0	2639.2	1068.1	1777	719.1	1766.1	714.7	
Other	347.9	140.8	604.3	244.5	386.7	156.5	1342.3	543.2
Total	26188.6	10589.2	26188.8	10589.2	26189.6	10589.6	26189.8	10589.6

identified within the Grand Bayou study area, but still no saline marsh was reported in the Lake Boudreaux area.

In 1978, an area in the western portion of the study area that had marsh on the western side and more open water on the east was designated as aquatic vegetation. Dr. W. Gagliano (personal communication) has considered this area as a location of a subsurface fault. Another area of aquatics was noted along the western border next to Lake Boudreaux, and is included in the “water” category. Clumps of aquatics were located in the middle of the study area.

As seen in Table 2.7 the total marsh area decreased over 2200 ac between 1978 and 1988/90. Intermediate marsh encroached into fresh marsh, as did brackish into intermediate (figures 2.4b and c). Still no saline marsh was reported in the study area.

The water category increased over 45% during the ten years from 1978 to 1988. Comparing figures 2.4b and c, one can see that much of the area reported as brackish in 1978 had become open water by 1988. An almost linear area of water opened up in the eastern part of the study area, trending to the west in the upper reaches of the study area. The area of shrub/scrub south of the 1978 intermediate/fresh boundary mostly became open water by 1988/1990. The shrub/scrub for 1990 was then on the western edge of the study area. The 1993 Land/Water analysis (figure 2.3d) showed that open water had increased in the fresh and intermediate areas, and in the northern brackish areas.

Figure 2.5 shows that by 1998, the western “leg” of the study area supported saline marsh. This is the first documentation of saline marsh within the study area. Some encroachment of intermediate marsh into the fresh marsh occurred, with the fresh marsh covering slightly less area than in 1990. Intermediate marsh covered only about 10 more acres than in 1988. The intermediate/brackish lines shifted southward somewhat. In 1998 some intermediate marsh was located within the brackish marsh along water bodies. Wax myrtles were still present throughout the study area, in fresh to brackish marshes. Groundtruthing data from 2001 showed that the southernmost wax myrtles located just north of Lake Boudreaux that had a live wax myrtle signature in 1998 had died, with trunks still standing.

### **1998 Habitat Analysis**

#### *Grand Bayou*

##### *General Description*

The general marsh zones in 1998 for the Grand Bayou study area are shown in Figure 2.6. The marsh covered 34924.2 ac in the study area. Most of the marsh was mesohaline (22228.1 ac), covering approximately the lower two-thirds of the marsh area. Oligohaline marsh was located in an east-west band across the study area between the fresh and mesohaline marshes, covering 7651.0 ac. Fresh marsh was located along the northern edge of the study area in a wedge shape that was wider in the west than in the east, accounting for 4679 ac of the marsh. Polyhaline marsh represented an isolated stand of *Spartina alterniflora*. It was located in the northwestern portion of the study area in a niche surrounded by mesohaline marsh, and surrounding a pocket of oligohaline marsh. Wax myrtles were found in patches within the fresh and intermediate marshes and along the fresh/intermediate boundary, accounting for 500 ac. Other forests and trees covered about 3260 ac in the study area. Canal and associated spoil criss-crossed the study area, covering 5678 ac. Open water accounted for 12063 ac, and other non-marsh habitats covered 939.3 ac.

Figure 2.7 shows the location of the class values, while figure 2.8 summarizes the class (that is, percentage of land and water within the marshes) within the Grand Bayou study area by

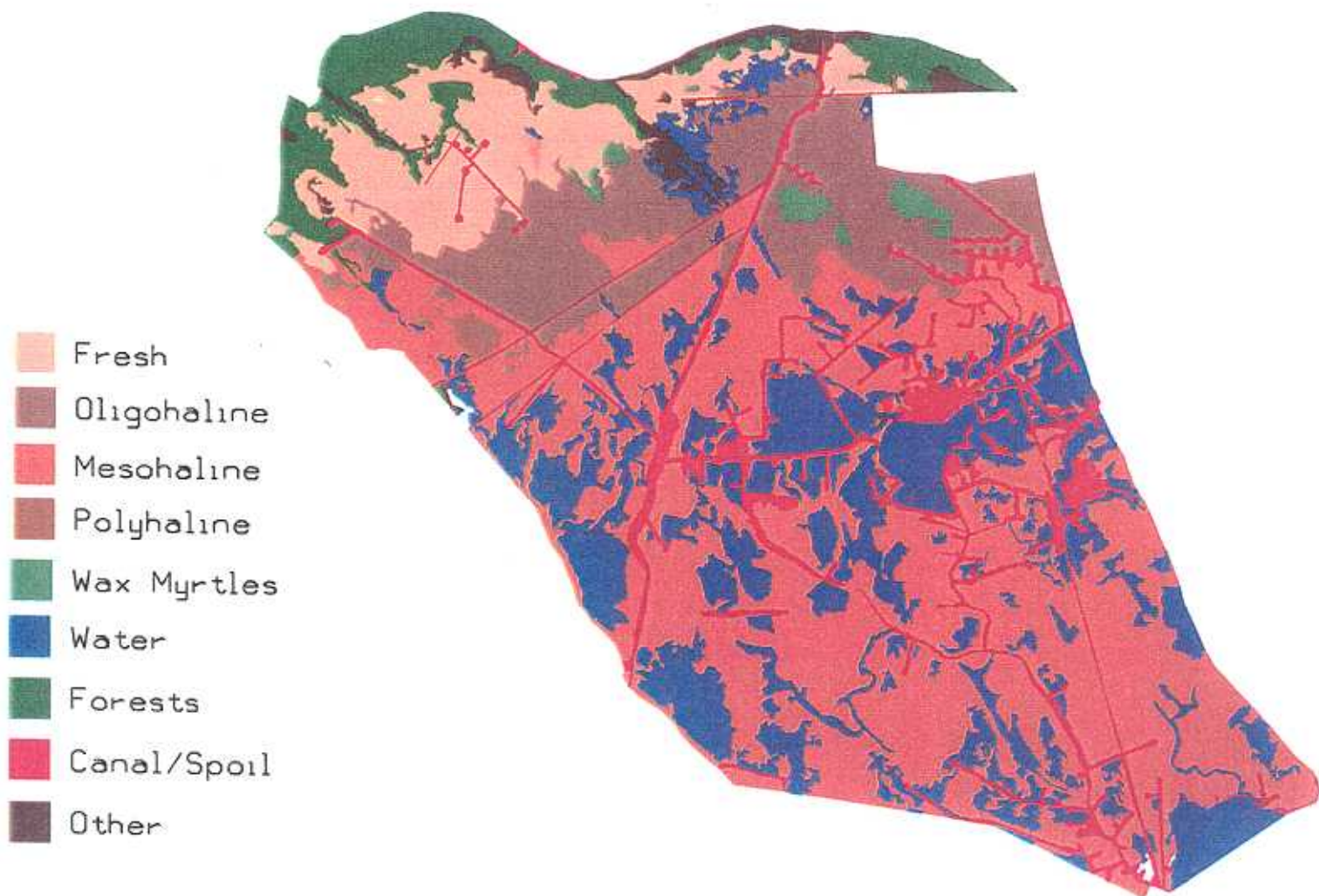


Figure 2.6. The general marsh zones as determined by vegetation types in the Grand Bayou study area.

four marsh types, with class 1 representing solid marsh, and class 6, areas of marsh within larger areas of 60 to 80% open water areas. We used percentages of each class within the marsh area to be able to compare both of our study areas. Most of the marsh in the Grand Bayou study area was in class 5 (13852 ac), followed by class 4 (8387 ac), with the smallest quantities being in classes 1 and 2, indicating that the marshes overall are currently severely degraded. Both the fresh and oligohaline marshes were predominately in class 3, (37.2% of the fresh marsh and 47.0% of the oligohaline marsh in class 3), while mesohaline and polyhaline were in class 5 (48.0% and 79.7%, respectively).

Figure 2.9 plots the configurations in the Grand Bayou study area. Figure 2.10 summarizes the configuration of water bodies within the marsh by general marsh zone. The “a” configuration indicates individual, elongated, randomly spaced water bodies separated by solid marsh. Configuration “b” represents marsh with smaller, individual water bodies sprinkled throughout the marsh landscape. The “c” indicates less intact marsh, in a region of large and small water bodies within a weaker marsh matrix, having a mixture of both configurations “a” and “b” within the marsh. We consider that the “c” configuration indicates the most degraded marshes of the three configurations. Classes 1 and 6 have no modifiers since they represent the endpoints of the marsh degradation process. The majority of the Grand Bayou study area marshes (78.1%) exhibited either the “a” configuration (15,003 ac) or “c” (12,270 ac). The Grand Bayou fresh and oligohaline marshes were dominated by category “a” marsh, with 83.2% and 58.6% respectively. Mesohaline and polyhaline marshes in the study area were dominated by category “c” marsh (44.8% and 60.7%, respectively), denoting that these marshes were more degraded than the fresher marshes.

### *Fresh Marsh*

Table 2.8 provides a summary of the categories of marsh/land configuration for each marsh type in the Grand Bayou study area, with Table 2.2 defining the marsh types. Figure 2.11 shows the location of the vegetation types found in the Grand Bayou area. Most of the 4,679 ac of fresh marsh was in category 3a (1,393 ac), followed by class 5a (1,148 ac). All classes were present in the fresh marsh. As shown in figures 2.7 and 2.8, more fresh marsh was in classes 3 and 5. Figures 2.9 and 2.10 show that over 80% of the fresh marsh were configuration “a”, making this the most common configuration in fresh marsh.

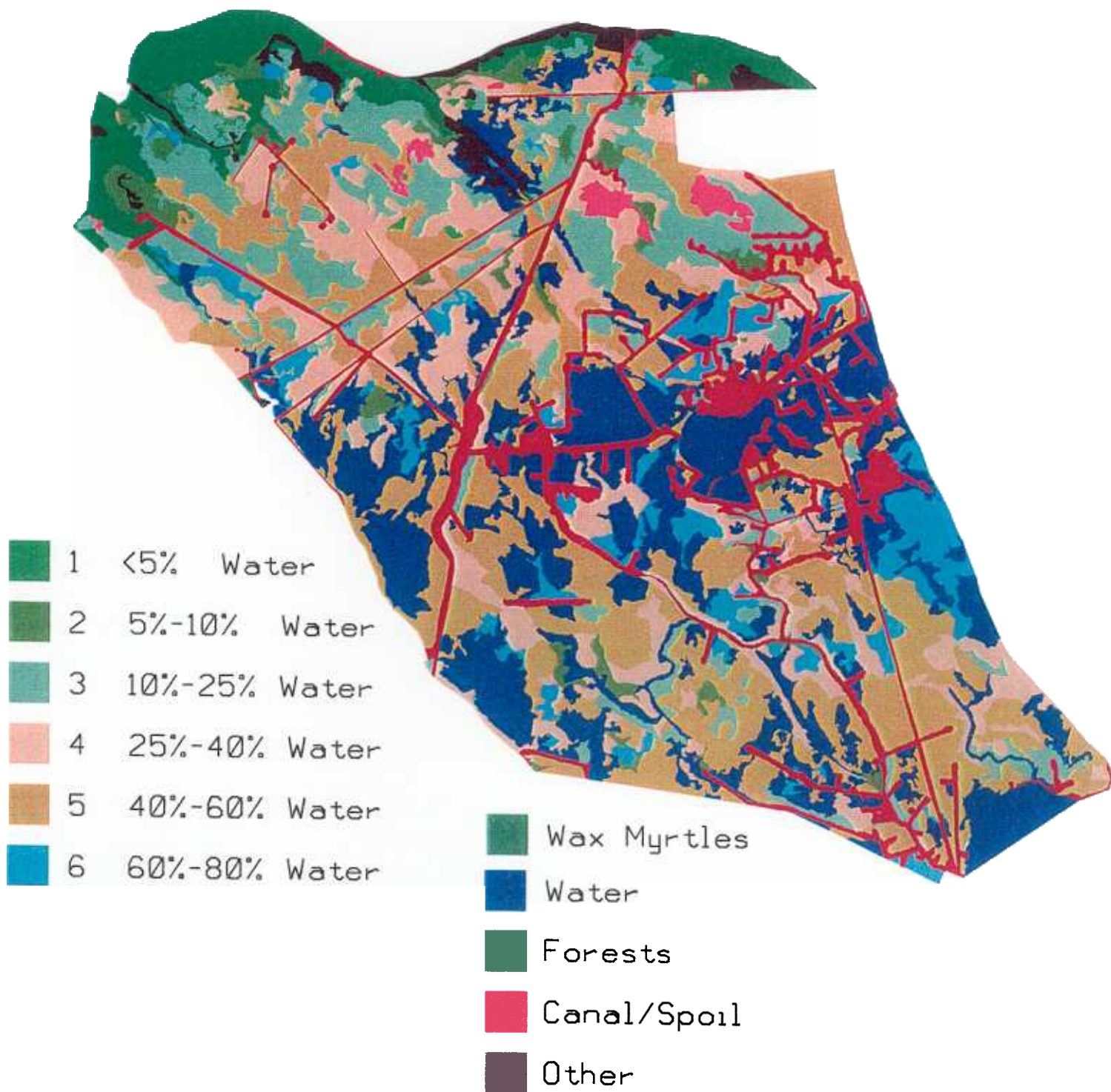


Figure 2.7. Class summary of the Grand Bayou study area.

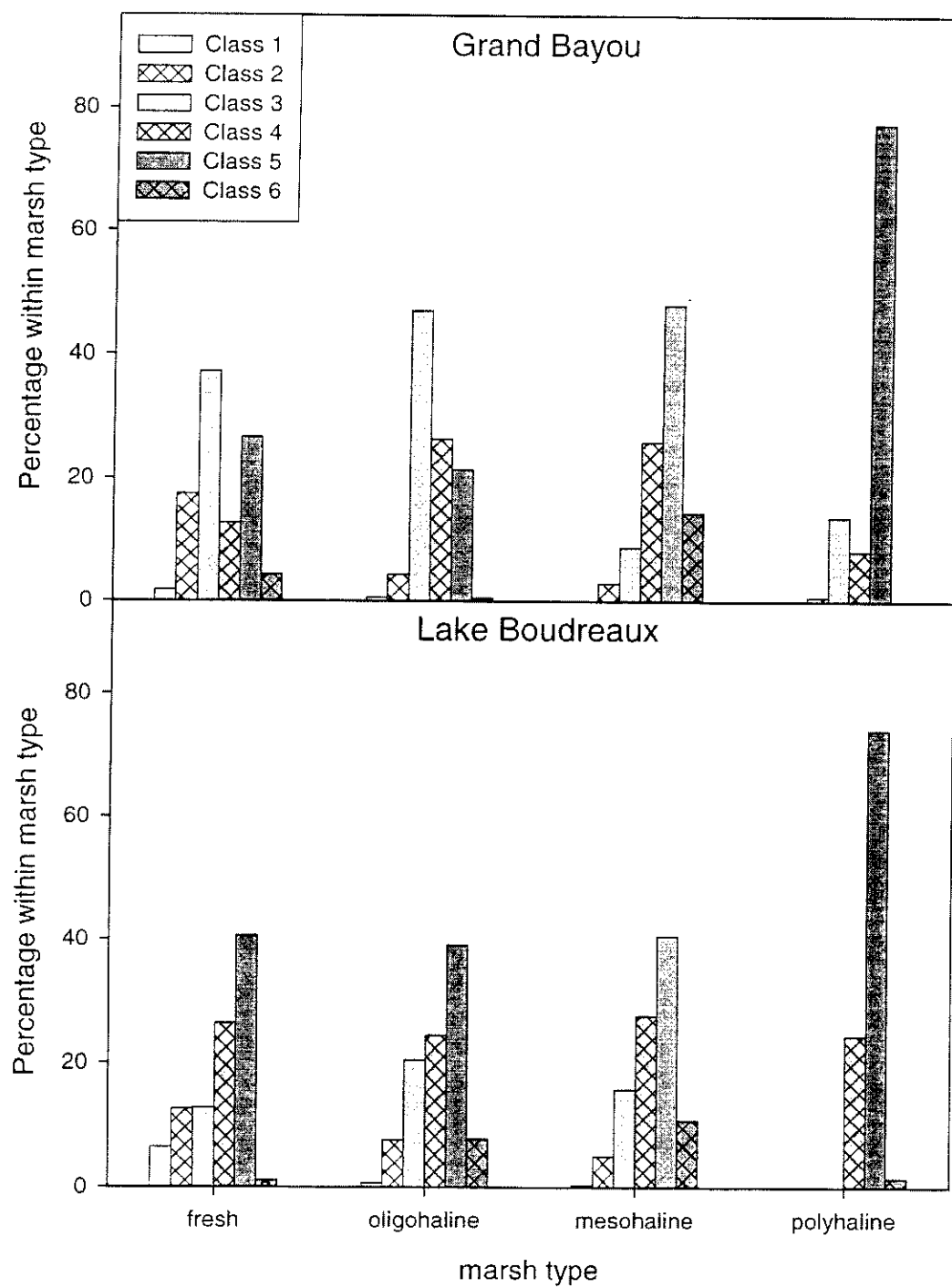


Figure 2.8. A summary of the classes in the Grand Bayou and Lake Boudreaux study areas.

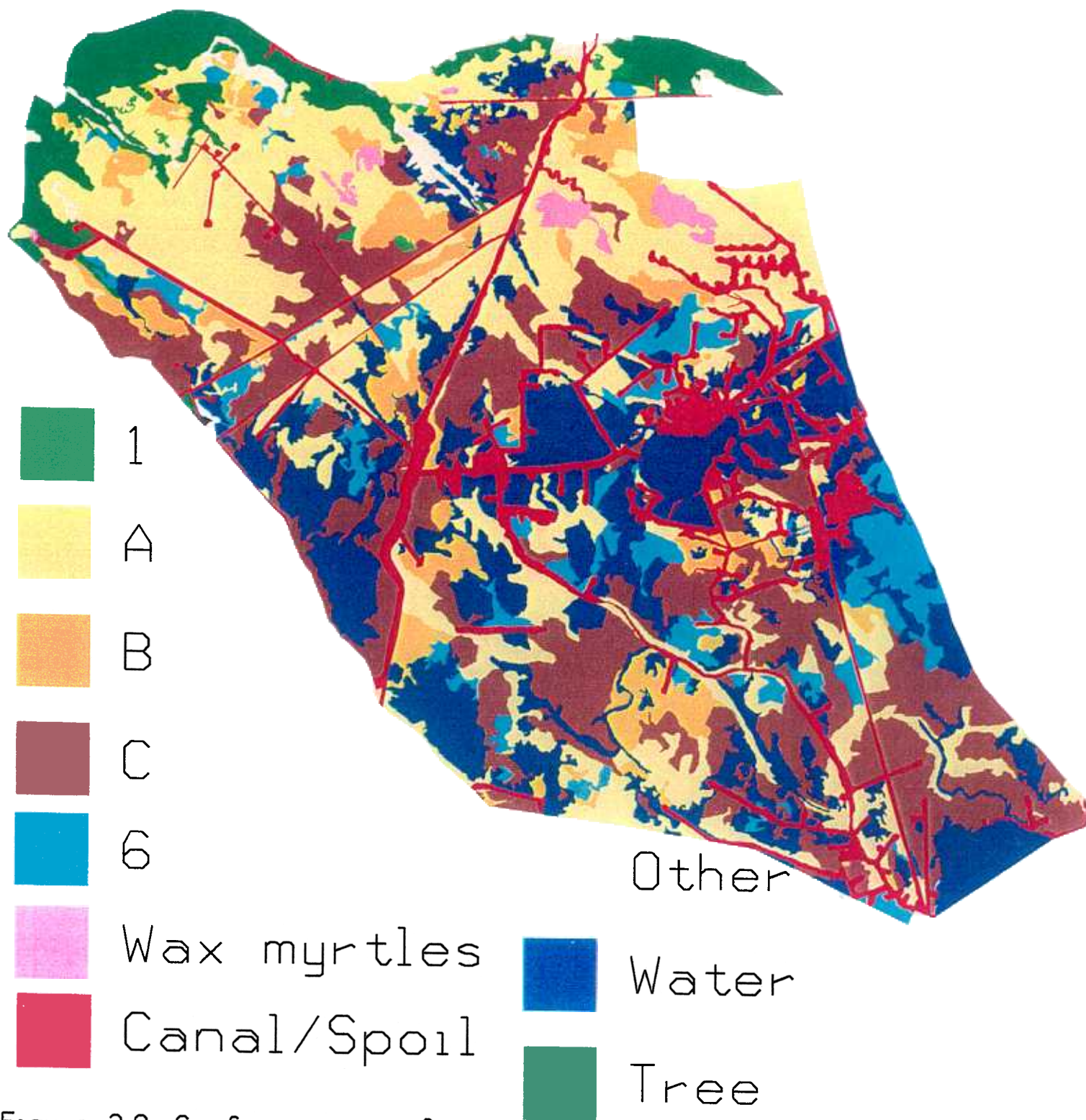


Figure 2.9. Configurations of marsh in the Grand Bayou study area.

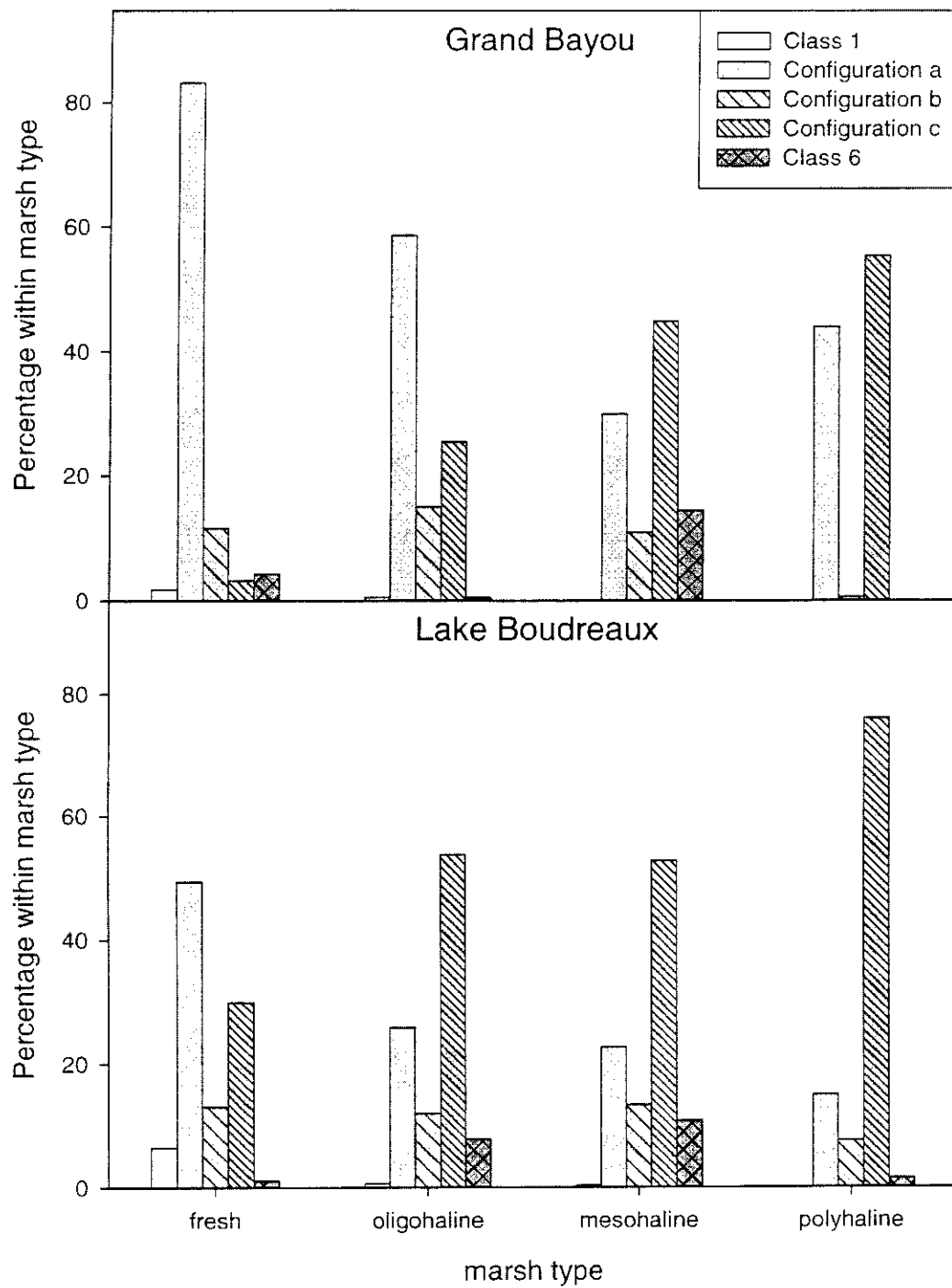


Figure 2.10. A summary of the configurations in the Grand Bayou and Lake Boudreaux study areas.

Table 2.8. A summary of the marsh area within vegetation types (acres) at Grand Bayou, along with the category in which they were identified. Totals for each marsh type are included in bold type.

	I	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6	Water	CSP	Trees	Other	Total
Fresh maidencane	35.3	426.3	31.9		377.9	141.8		9.1			91.6								1114.0
Fresh bulltongue	27.9	62.5			867.7		47.9	210.2	59.0	38.0	916.9	24.2	32.4	164.3					2451.0
Fresh spikerush	22.2	272.9	18.0		147.2	157.3		205.8	72.1		138.6	15.8	26.7	36.3					1113.0
Scirpus validus																			
Typha sp.																			
<b>Fresh Marsh Total</b>	<b>86.4</b>	<b>763.7</b>	<b>41.9</b>		<b>1395.8</b>	<b>299.4</b>	<b>47.9</b>	<b>429.1</b>	<b>131.1</b>	<b>38</b>	<b>1152.1</b>	<b>40</b>	<b>59.1</b>	<b>200.6</b>					<b>3793.1</b>
Wax myrtle	2.7	171.4	182.5					100.5				36.3							499.2
Oligohaline bulltongue	40.3	106.5		49.4	1311.1		357.9	66.2	119.3	800.5	510.8	45.4	471.8	29.6					3879.1
Oligohaline paspalum transition		143.0		17.3	1434.3	193.2	93.4	397.9	286.8	49.6	253.2	155.4	69.9						3093.9
Oligohaline wiregrass		1.2		9.4	76.1	129.2		48.9	220.1	25.4	129.4								639.7
<b>Oligohaline Marsh Total</b>	<b>40.3</b>	<b>250.7</b>		<b>76.1</b>	<b>2821.5</b>	<b>322.4</b>	<b>451.3</b>	<b>513</b>	<b>626.2</b>	<b>875.5</b>	<b>893.4</b>	<b>200.8</b>	<b>541.7</b>	<b>29.6</b>					<b>7612.7</b>
Mesohaline mix		137.1	90.2	187.7	267.7	432.5	519.4	1580.1	258.4	1280.4	2056.0	874.4	3770.9	1852.7					13307.6
Mesohaline wiregrass		118.1	4.4	114.1	144.5	160.8	436.0	1081.4	544.9	998.6	1265.6	61.0	2645.4	1336.0					8910.8
<b>Mesohaline Marsh Total</b>	<b>255.2</b>	<b>94.6</b>	<b>301.8</b>	<b>412.2</b>	<b>593.3</b>	<b>593.3</b>	<b>955.4</b>	<b>2661.5</b>	<b>803.3</b>	<b>2279</b>	<b>3321.6</b>	<b>935.4</b>	<b>6416.3</b>	<b>3188.7</b>					<b>22218.3</b>
<b>Polyhaline</b>			<b>2.5</b>	<b>41.0</b>	<b>14.2</b>		<b>35.2</b>			<b>30.9</b>	<b>100.3</b>		<b>191.2</b>						<b>400.9</b>
Water															12041.3				12041.1
Canals																5671.1			5671.1
Trees																	3257.9		3257.9
Other																	938.8		938.8
<b>Total</b>	<b>134.1</b>	<b>1439.0</b>	<b>329.5</b>	<b>418.9</b>	<b>4626.6</b>	<b>1214.7</b>	<b>1454.6</b>	<b>3700.1</b>	<b>1560.5</b>	<b>3223.6</b>	<b>5462.4</b>	<b>1212.5</b>	<b>7208.2</b>	<b>3419.0</b>	<b>12096.3</b>	<b>5671.1</b>	<b>3257.9</b>	<b>938.8</b>	<b>57368.0</b>

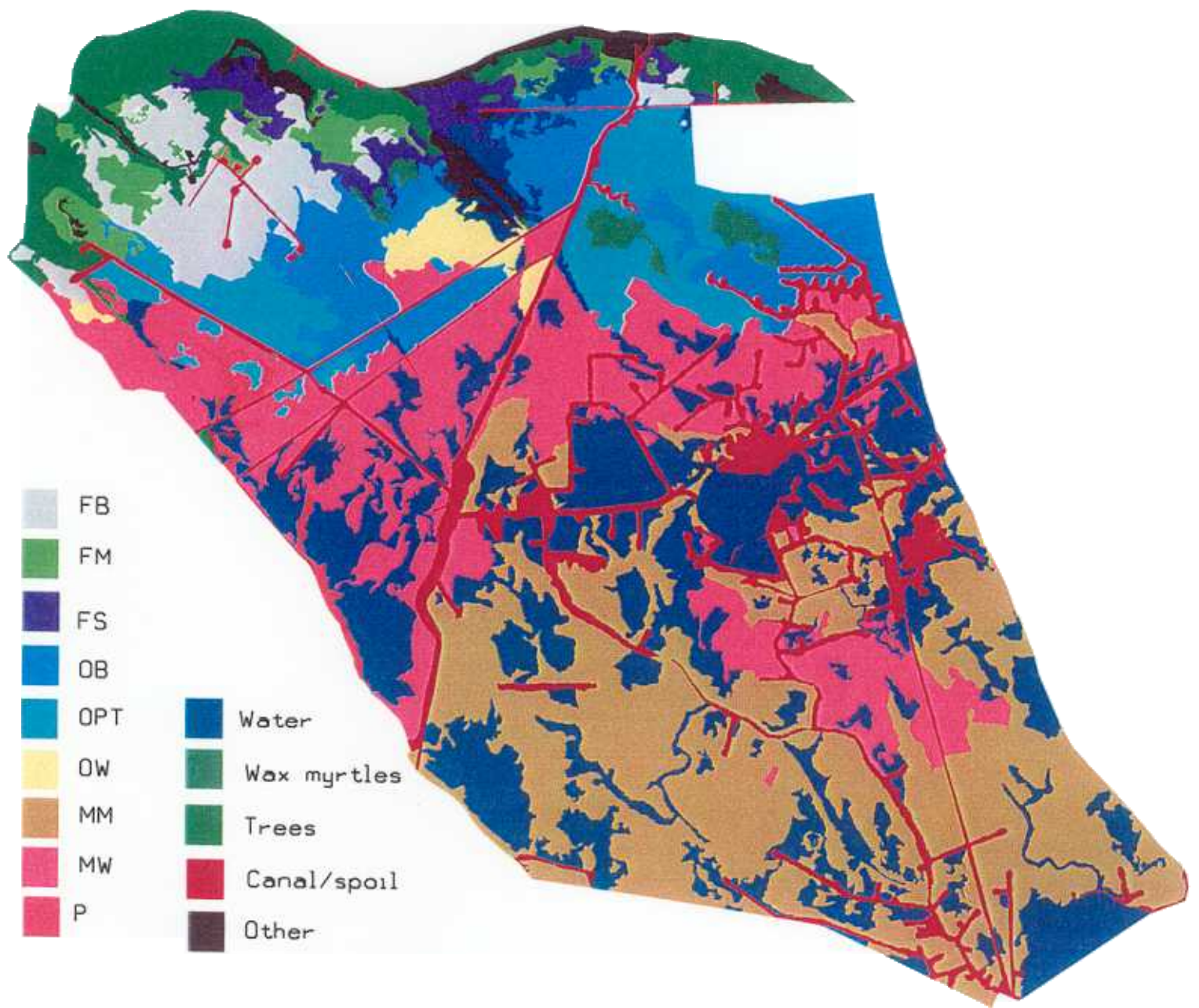


Figure 2.11. The marsh vegetation types in the Grand Bayou study area.

Fresh Maidencane (FM) vegetation type accounted for 1,130 ac in the Grand Bayou study area. Most of this seemed fairly healthy, that is, in categories 2a (38.3%) and 3a (33.9%). No FM was classified as class “c”, along with none in categories 4b, 4c, 5b, 5c, and 6. Table 2.9 shows that most of FM was in classes 2 and 3 (that is, with 5%-25% open water). Table 2.10 shows that 84% of FM was category “a”. These indicators both point to a reasonably “healthy” FM marsh.

The Fresh Bulltongue (FB) vegetation type covered the largest area within the fresh marsh (2,452 ac). The FB vegetation type was more degraded than was the FM type, as indicated by FB mostly occurring in categories 3a (35.4%) and 5a (37.4%). Just less than 50% of FB type was found in classes 3 and 4, indicating a marsh with 10% to 40% water within the marsh. Another 40% of the FB marsh were in class 5, representing 40-60% open water. Most of the FB vegetation type (91.1%) was configuration “a”. This shows that, even though the marshes are degrading, the process is probably through erosion of larger water bodies, rather than through new water pockets forming within the marsh complex.

The Fresh Spikerush (FS) vegetation type covered 1098 ac. It was much more common in the Grand Bayou area than in the Lake Boudreaux study area. FS was spread among several categories, including 2a (24.5%), 3a (13.2%), 3b (14.1%), 4a (18.5%), and 5a (12.5%). More than 75% of FS was in classes 2, 3, and 4, with 72% in configuration “a”. The Wax Myrtle (WM) vegetation category was located along the fresh/intermediate border, and also within the intermediate marsh. The 500 ac of WM were usually found in larger clumps of at least 17 ac.

### *Oligohaline Marsh*

The oligohaline marsh accounted for 7,651 ac of the Grand Bayou study area. Every category except 2b was represented. Most of oligohaline marsh was classified as category 3 (3,597 ac). Configuration “a” had by far the largest representation (59%, figure 2.10) and class 3 (47%, figure 2.8), the largest class. Oligohaline marsh comprised several vegetation types, including Oligohaline Bulltongue (OB), covering 2,749 ac, and Oligohaline *Paspalum* Transition (OPT), with 3,094 ac, and Oligohaline Wiregrass, 640 ac.

The OB vegetation type occurred mostly in categories 3a (34%) and 4c (21%). OB was found mostly in class 3 (43%), with 51% more found in classes 4 and 5. With <5% of OB in

configuration “b”, the rest was divided between “a” (51.0%) and “c” (43.1%). Based on the high percentage of configuration “c” in the OB vegetation type, OB represents a marsh type more degraded than the fresh FB marsh type in the Grand Bayou area, having pockets of water within the marsh, as well as the shoreline erosion present in the FB areas. OB was located as large areas south of FB marshes. The main difference between FB and OB is the presence of *Panicum hemitomon* in the FB type, and its absence in OB.

The Oligohaline *Paspalum* Transition (OPT) vegetation type was the largest oligohaline type, with 3,094 ac. OPT represents a marsh that may contain *Sagittaria lancifolia*, but not as the dominant species. Species such as *Paspalum vaginatum* and *Amaranthus australis* were more dominant. None of OPT occurred in classes 1 or 6. Most was in category 3a (46.4%), with 56% of all OPT in class 3, and 72% in configuration “a”.

The Oligohaline wiregrass (OW) vegetation type represented the smallest area in the oligohaline marsh, with 640 ac. OW is dominated by *Spartina patens*, and does not contain more salt-tolerant species such as *Distichlis spicata* and *Spartina alterniflora*. Over one-third of the OW was categorized as 4b, with 20% each in 3b and 5a. OW was most represented in class 4 (46%), with 32% in class 3 and 20% in class 5. Configurations “a” and “b” accounted for 40% and 55%, respectively.

#### *Mesohaline Marsh*

Mesohaline marsh covered the largest marsh area within the Grand Bayou area, representing 22,228 ac, or 63.6% of the marsh area. The largest class of mesohaline marsh was 5 (48%, figure 2.8), while the largest configuration grouping was “c” (45%, figure 2.10). This marsh was more degraded than the fresher types.

Mesohaline Mixture (MM) vegetation type accounted for 60% (13,313 ac) of the mesohaline marsh. Over 87% of MM were categorized as 4a through 6, with 28.3% in category 5c. Over 50% of MM were in class 5, and in configuration “c”. MM may have contained *S. patens*, but is not necessarily dominated by it. *Distichlis spicata* and *Spartina alterniflora* are present also.

The Mesohaline Wiregrass (MW) vegetation type is dominated by *Spartina patens*, with other species possibly present. Over 89% of the 8,915 ac of MW were grouped into categories 4a

Table 2.9. A summary of the class indicator for the Grand Bayou and Lake Boudreaux study areas by vegetation type. Percentages of totals for each marsh type were used for comparison purposes.

Vegetation Type	Class	Grand Bayou	Lake Boudreaux
<b>Fresh Marsh Types</b>			
Fresh maidencane	1	3.2%	19.1%
	2	41.1%	11.5%
	3	46.7%	13.7%
	4	0.8%	25.9%
	5	8.2%	29.8%
	6	0.0%	0.0%
Fresh bulltongue	1	1.1%	0.3%
	2	2.5%	5.4%
	3	37.4%	10.8%
	4	12.5%	30.0%
	5	39.7%	51.8%
	6	6.7%	1.8%
Fresh spikerush	1	2.0%	
	2	26.1%	100.0%
	3	27.4%	
	4	25.0%	
	5	16.3%	
	6	3.3%	
Scirpus validus	1		75.8%
	2		2.3%
	3		3.9%
	5		18.0%
Typha sp.	2		63.5%
	3		27.2%
	4		9.3%
<b>Oligohaline Marsh Types</b>			
Oligohaline bulltongue	1	1.0%	1.0%
	2	4.0%	2.2%
	3	42.7%	29.7%
	4	25.2%	27.9%
	5	26.3%	36.5%
	6	0.8%	2.7%
Oligohaline paspalum transition	1		0.5%
	2	5.2%	5.2%
	3	55.6%	16.6%
	4	23.7%	18.1%
	5	15.5%	53.9%
	6		5.6%
Oligohaline wiregrass	1		0.4%
	2	1.7%	12.0%
	3	32.1%	16.3%
	4	46.0%	25.1%
	5	20.2%	34.3%
	6		11.9%

Table 2.9. (Continued).

Vegetation Type	Class	Grand Bayou	Lake Boudreaux
<b>Mesohaline Marsh Types</b>			
Mesohaline mix	1		
	2	3.1%	5.6%
	3	9.2%	0.9%
	4	23.4%	42.7%
	5	50.4%	41.7%
	6	13.9%	9.1%
Mesohaline wiregrass	1		0.3%
	2	2.7%	4.9%
	3	8.3%	16.8%
	4	29.5%	26.5%
	5	44.6%	40.5%
	6	15.0%	10.9%
<b>Polyhaline Marsh Type</b>			
	1		
	2	10.8%	
	3	8.7%	
	4	7.7%	24.4%
	5	72.7%	74.2%
	6		1.5%

through 6, with 29.7% in class 5c. Forty-five percent of MW was in class 5, followed by 30% in class 4. Over 55% of MW were in configuration “c”.

#### *Polyhaline Marsh*

The polyhaline marsh represented the smallest marsh category in the Grand Bayou study area. It comprised mostly a *Baccharis halimifolia* – type marsh (60.7%) on old ridges. The remainder of this marsh type is polyhaline oystergrass (PO). The PO type was found as a pocket of saline marsh in the northwestern portion of the study area surrounded by mesohaline marsh, and surrounding an area of OPT marsh. Most of the polyhaline marsh was found in class 5, and configuration “c” (72%), indicating that this marsh is a degraded marsh.

Table 2.10. A summary of the configurations by vegetation type for the Grand Bayou and Lake Boudreaux study areas. Percentages of totals for each marsh type were used for comparison purposes.

Vegetation Type	Configuration	Grand Bayou	Lake Boudreaux
<b>Fresh Marsh Types</b>			
Fresh maidencane	A	83.9%	72.4%
	B	16.1%	19.7%
	C		7.9%
Fresh bulltongue	A	91.1%	50.2%
	B	3.7%	8.6%
	C	5.2%	41.1%
Fresh spikerush	A	72.5%	
	B	25.0%	100.0%
	C	2.5%	
Scirpus validus	A		25.8%
	B		
	C		74.2%
Typha sp.	A		36.3%
	B		40.1%
	C		23.6%
<b>Oligohaline Marsh Types</b>			
Oligohaline bulltongue	A	52.0%	16.5%
	B	4.3%	7.1%
	C	43.8%	76.3%
Oligohaline paspalum transition	A	72.0%	29.4%
	B	20.5%	3.4%
	C	7.4%	67.2%
Oligohaline wiregrass	A	40.0%	35.8%
	B	54.6%	21.8%
	C	5.4%	42.4%
<b>Mesohaline Marsh Types</b>			
Mesohaline mix	A	35.3%	10.0%
	B	14.5%	1.8%
	C	50.3%	88.2%
Mesohaline wiregrass	A	34.5%	26.7%
	B	10.2%	16.0%
	C	55.4%	57.2%
<b>Polyhaline Marsh Type</b>	A	33.8%	15.2%
	B	0.6%	7.7%
	C	65.6%	77.1%

## *Lake Boudreaux*

### *General Description*

Figure 2.12 shows the general marsh vegetation zones in the Lake Boudreaux study area. The marsh covered 12,440 ac in the study area. The greatest portion of the marsh area was mesohaline (5,981 ac), located in the lower two thirds of the eastern side of the study area. The oligohaline marsh covered 4,518 ac, located primarily on the western side of the study area, south of the forested area. Fresh marsh covered 1,655 ac in the upper northeastern section. A relatively small area of polyhaline marsh (286 ac) was located in the lower western “leg” of the study area. Areas of wax myrtles (*Myrica cerifera*) were found throughout the study area, accounting for 1,766 ac, while other trees covered another 2,588 ac. The canal/spoil network criss-crossed the study area, covering 2,047 ac. Other non-marsh areas covered 1,342 ac.

Table 2.12 summarizes the acreage for each vegetation type for the Lake Boudreaux study area. Figure 2.13 shows that class 1 was found mostly in the northern section of the study area, in the fresh marsh area. Class 2 was found mostly in the western section, near the forested area, and the lower half of the study area. Neither this class nor class 3 was found in the polyhaline marsh areas. Class 3 was found mostly in the mesohaline and oligohaline marshes, located both in the northeastern portion and in the southern half of the study area. Class 4 was found throughout the study area. In every marsh type, class 5 designated the largest area, indicating that the marsh was already severely degraded. Category 6 was often located next to open water, indicating that the water areas are enlarging from the shoreline inward into the marshes.

Most of the polyhaline marsh was within class 5 (74.1%), and the other three marsh types had approximately 40% in that class, making class 5 the largest class within the Lake Boudreaux study area (Figure 2.8). Fresh marsh was mostly in classes 2 and 3 (12.6 and 12.8% respectively). Oligohaline marsh was most highly represented in classes 4 (24.5%) and 3 (20.5%). Less than seven percent of each marsh type was in class 1. No polyhaline marsh was in classes 1 through 3.

Figure 2.14 summarizes the configuration of water bodies within the marsh. Most of the fresh marsh (817 ac, 54%) was in category “a” (figure 2.10), while category “c” accounted for over 50% of each of the other marsh types.

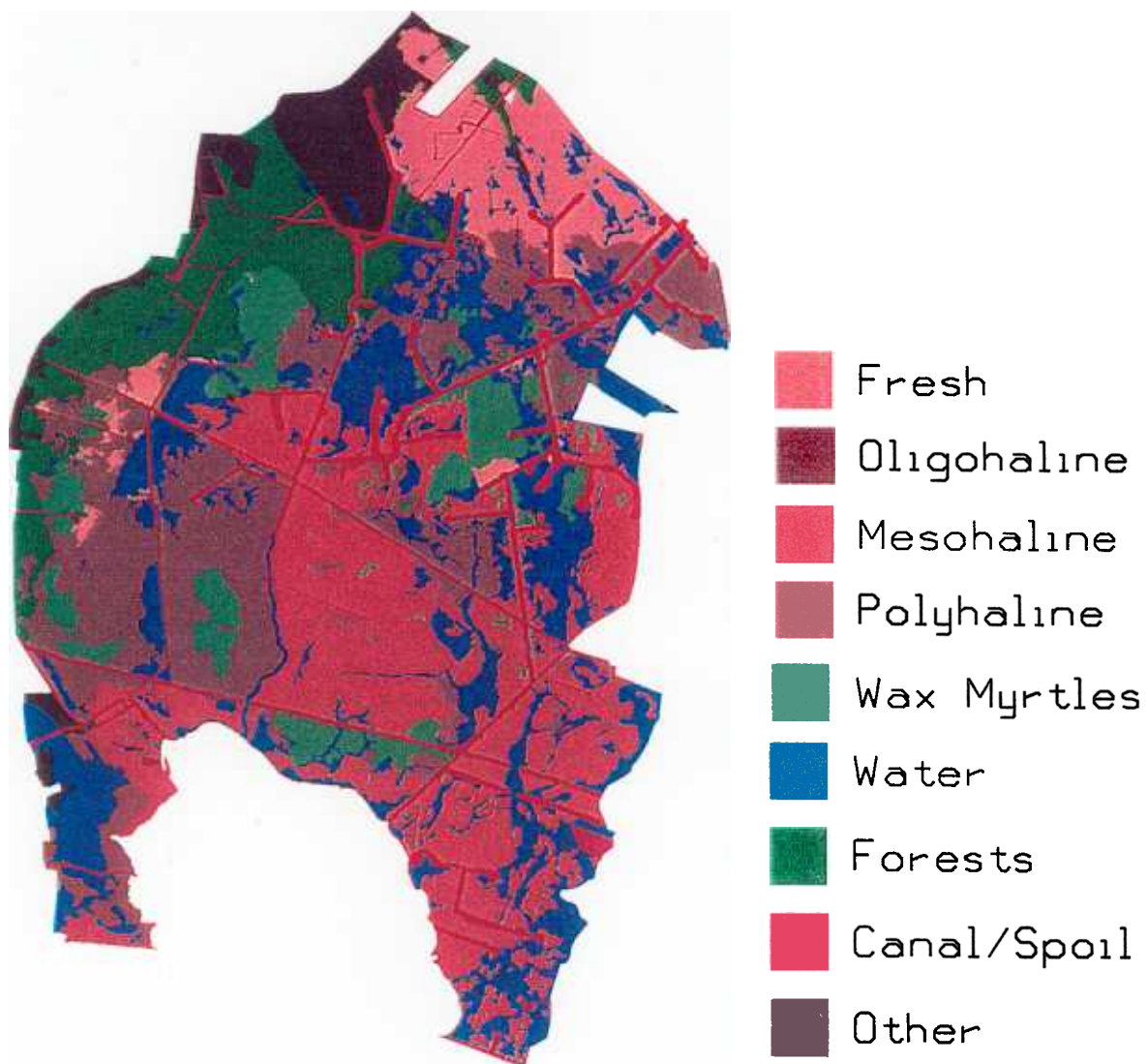


Figure 2.12. Genreal marsh zones in the Lake Boudreaux study area.

Table 2.12. A summary of the marsh area (acres) within vegetation types at Lake Boudreaux, along with the category in which they were identified. Totals for each marsh type are included in bold type:

	1	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6	Water	CSP	Trees	Other	Total
Fresh maidencane	80.5	21.5		26.9	38.0	19.5		108.9			77.8	47.7							420.9
Fresh bulltongue	2.7	30.4	24.2	1.7	35.8	36.1	40.3	205.0		107.9	242.1	27.9	270.2	18.3					1042.6
Fresh spikerush			7.2																7.2
Scirpus validus	24.0	0.7			1.2								5.7						31.6
Typha sp.		33.8	42.2	20.3	8.2	17.5	15.6	13.1	1.0										151.7
<b>Fresh Total</b>	<b>107.2</b>	<b>86.4</b>	<b>73.6</b>	<b>48.9</b>	<b>83.2</b>	<b>73.1</b>	<b>55.9</b>	<b>327.0</b>	<b>1.0</b>	<b>107.9</b>	<b>324.9</b>	<b>80.6</b>		<b>18.3</b>					<b>1654.0</b>
Wax myrtle	247.0	147.5	6.2	19.3	56.3	9.1	13.8	292.2	58.5	2.2	496.2	60.3	156.6	200.1					1765.3
Oligohaline bulltongue	13.8	7.2		22.7	85.0	17.0	307.0	28.7	57.3	298.6	98.6	20.5	384.3	36.8					1377.5
Oligohaline paspalum transition	4.9	24.7		24.5	28.2	8.4	121.0	39.3	6.2	126.0	169.4	15.6	325.1	53.4					946.6
Oligohaline wiregrass	2.5	106.5	8.6	148.7	134.6	183.3	40.0	86.5	206.7	256.6	359.9	20.5	370.7	260.8					2192.4
<b>Oligohaline Total</b>	<b>21.2</b>	<b>138.4</b>	<b>8.6</b>	<b>195.9</b>	<b>247.8</b>	<b>208.7</b>	<b>468</b>	<b>154.5</b>	<b>270.2</b>	<b>681.2</b>	<b>627.9</b>	<b>56.6</b>	<b>1080.1</b>	<b>351</b>					<b>4516.5</b>
Mesohaline mix				21.5	1.7		1.7	19.8		143.0	13.3	6.2	139.6	34.6					381.4
Mesohaline wiregrass	16.8	108.9	46.2	119.5	349.8	267.0	323.1	419.9	448.3	616.5	449.0	35.3	1784.1	612.3					5596.8
<b>Mesohaline Total</b>	<b>16.8</b>	<b>108.9</b>	<b>46.2</b>	<b>141</b>	<b>351.5</b>	<b>267</b>	<b>324.8</b>	<b>439.7</b>	<b>448.3</b>	<b>759.5</b>	<b>462.3</b>	<b>41.5</b>	<b>1923.7</b>	<b>646.9</b>					<b>5978.2</b>
Polyhaline oystergrass								<b>42.7</b>		<b>26.9</b>		<b>21.7</b>	<b>190.4</b>	<b>4.2</b>					<b>286.0</b>
Water															6002.6				6002.6
Canals																2045.9			2045.9
Trees																	2587.3		2587.3
Other																		1341.7	1341.7
<b>Total</b>	<b>398.7</b>	<b>481.2</b>	<b>134.6</b>	<b>405.1</b>	<b>738.8</b>	<b>558.0</b>	<b>862.5</b>	<b>1256.0</b>	<b>778.1</b>	<b>1577.8</b>	<b>1906.3</b>	<b>255.6</b>	<b>3626.8</b>	<b>1220.4</b>	<b>6002.6</b>	<b>2045.9</b>	<b>2587.3</b>	<b>1341.7</b>	<b>26177.4</b>

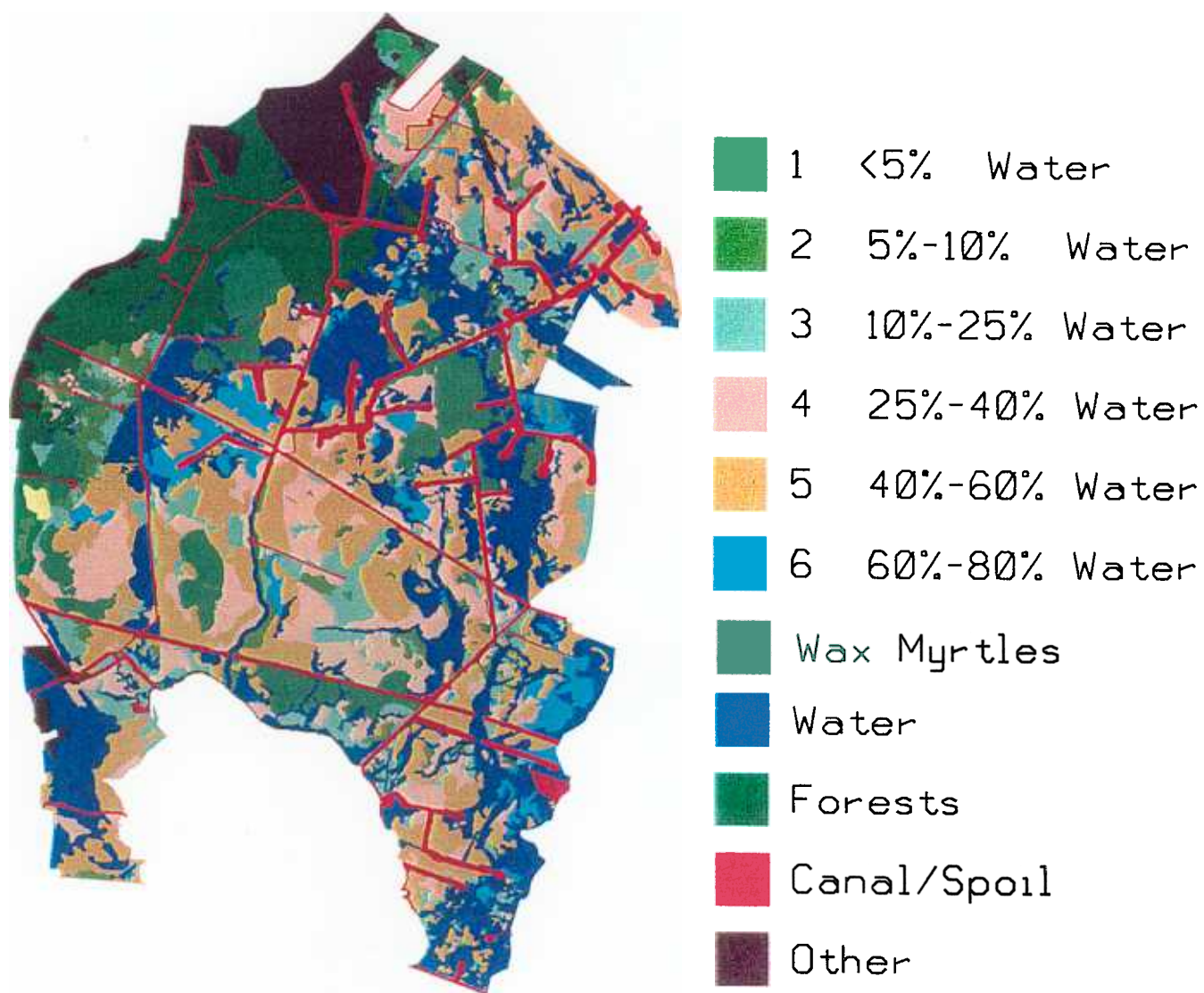


Figure 2.13. Class summary of the Lake Boudreaux study area.

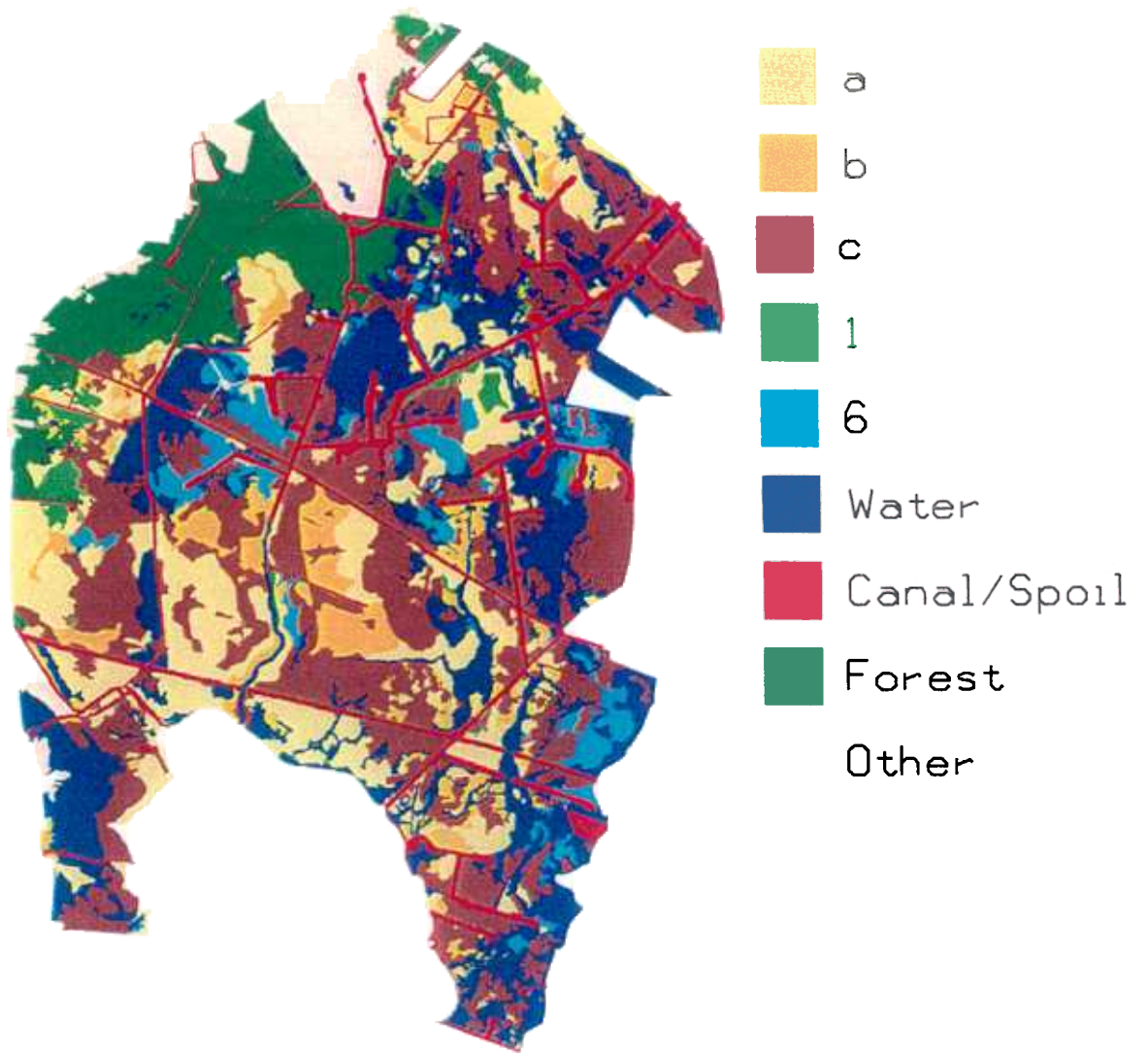


Figure 2.14. Configuration summary of the Lake Boudreaux study area.

### *Fresh marsh*

Figure 2.15 shows the location of the vegetation types in the Lake Boudreaux study area. The information in Tables 2.8 indicates that all of the fresh marsh in this study area was primarily in categories 4a and 5a, accounting for 647 ac (49.3%) of the fresh marsh. The '4's and '5's signified a degraded marsh, and the 'a' signified a matrix of larger, randomly-spaced water bodies that may be contiguous.

Fresh Maidencane (FM) vegetation type covered 421 ac (25.4%) of the fresh marsh, with 55.7% of the type in categories 4a, 5a, and 5b, and 44.3% in classes 1-3 (that is, <25% open water). The "a" configuration accounted for 58.5% of the fresh maidencane vegetation type. No category 6 was found in this vegetation type. As shown in figure 2.15, FM was found in the northernmost marsh area.

The Fresh Bulltongue (FB) vegetation type represented a more degraded vegetation type than did Fresh Maidencane. This category represented typical bulltongue marshes and those bulltongue marshes that were found to have many annual species. Fresh Bulltongue accounted for 1,044 ac (63.0%) of the fresh marsh vegetation, with 68.8% of FB found in categories 4a, 5a, and 5c, and only 16.5% in categories 1-3. By far, most of this vegetation type was degraded. The 1% of the fresh marsh that was in category 6 was found in the fresh bulltongue vegetation type that was transitioning to more annual species such as *Amaranthus australis*.

Only a small area (7 ac) of Fresh Spikerush was identified in the Lake Boudreaux area, located in a small pocket in the northern part of the study area. The *Typha* sp. vegetation type was found in the northwestern area of the study area, below the forested area. It accounted for 98.2% of the fresh marsh, and seemed to be relatively "healthy".

Thirty-one ac of *Scirpus validus*, found in the upper reaches of the marsh, was relatively healthy, (78.1% in categories 1 and 2a), and only 18.0% in a degraded pattern of 5c. The Wax Myrtle (WM) vegetation type is often associated with fresh maidencane marshes. In the Lake Boudreaux study area, this vegetation type was found throughout the study area, mostly in the oligohaline and mesohaline marsh areas. An area of dead wax myrtles was found approximately 250 ft inland from Lake Boudreaux. The signature in 1998 denoted that the trees were alive, but

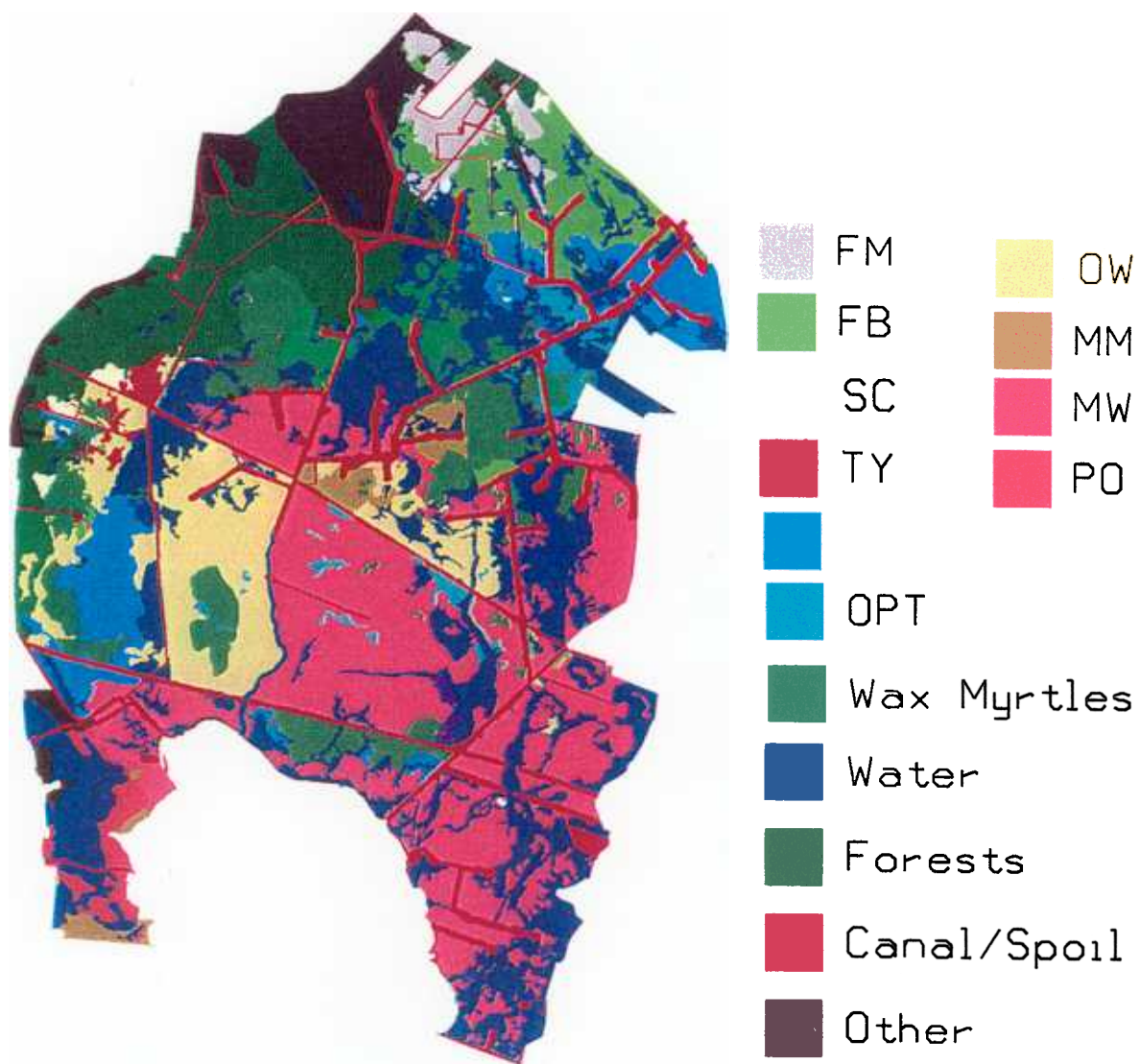


Figure 2.15. Vegetation types in the Lake Boudreaux study area.

by our groundtruthing expedition in 2001, they had died, with tree trunks and branches still standing. This vegetation type covered 1,766 ac of the study area.

### *Oligohaline Marsh*

The oligohaline marsh covered 4,518 ac (36.3%) of the marsh area in the Lake Boudreaux study area. Most of this marsh occurred along a northeast-southwest line across the study area. Over 50% of the oligohaline marsh was configuration “c” (figure 2.10), while over 40% was in class 5 (figure 2.8), showing that this marsh type was very degraded.

The Oligohaline Wiregrass (OW) vegetation type accounted for 48.5% of oligohaline marsh. OW was found near the OB marsh on its western edge, and bordering the mesohaline marsh in the east. Over half of the OW was in categories 4c, 5a, 5c, and 6, designating this marsh type as very degraded in the Lake Boudreaux study area.

Oligohaline Bulltongue (OB) covered 1,377 ac of oligohaline marsh, with 71% in categories 3c, 4c and 5c. Some of the OB areas represented a transition marsh type that included more annual species. Most of the OB marsh occurred along the western edge of the study area.

Oligohaline *Paspalum* Transition (OPT) vegetation type accounted for 849 ac (21.0%) of the oligohaline marsh category, south of the fresh marsh in an area of much open water. OPT represents a type of marsh that contains many species including *Paspalum vaginatum* and annuals, such as *Amaranthus australis*. OPT occurred 63% of the time in “c” configuration marshes, with half of the “c” included in the 5c category, indicating a high degree of degradation.

### *Mesohaline Marsh*

Greater than 40% of the mesohaline marsh in the Lake Boudreaux study area was identified as class 5 (figure 2.8), and over 50% of the area was designated as configuration “c” (figure 2.10). The 5,981 ac of mesohaline marsh comprised two vegetation types—Mesohaline Wiregrass (MW) and Mesohaline Mixed (MM)—with the MW type having by far the greatest acreage in the Lake Boudreaux study area.

The Mesohaline Wiregrass (MW) vegetation type covered 5,599 ac of the study area, representing the largest marsh category overall. It covered most of the southeastern quadrant of

the study area. Over 30% of the MW were categorized as 5c, representing a very degraded marsh.

The Mesohaline Mixed vegetation type occupied a niche near the oligohaline/mesohaline border. Over 72% of the MM vegetation type were classified as 4c or 5c each.

#### *Polyhaline Marsh*

The Polyhaline Oystergrass (PO) covered 286 ac of the study area, and comprised classes 4, 5, and 6 only, with 66.6% in the 5c category. PO was only found on the western “leg” of the study area, between a large water body and some mesohaline marsh.

### **Comparison of the Grand Bayou and Lake Boudreaux Study Areas**

Figure 2.16 is a summary of changes in total marsh area over time for the Grand Bayou and Lake Boudreaux study areas. Both study areas were mapped as 100% fresh and low salinity marshes in 1956, based on O’Neil’s 1949 vegetation map. Over time marsh area has decreased in both areas.

Within the Grand Bayou study area, the total marsh in 1978 covered approximately 10,000 ac less than that area in 1956, or 79% of the original 1956 marsh area (Table 2.5, figure 2.16). Table 2.7 shows that the Lake Boudreaux study area marsh decreased by approximately 6,500 ac between 1956 and 1978 to 69% of the area of marsh in 1956.

By 1978 the influence of salinity is noticeable, with fresh and low salinity marshes in the Grand Bayou study area decreasing from 49,286 ac in 1956 to a total of 21,613 ac of fresh and intermediate marsh in 1978. Fresh and low salinity marshes in the Lake Boudreaux study area decreased from 20,894 ac in 1956 to 12,192 ac of fresh and intermediate marsh in 1978. Intermediate marsh was the most common marsh type in Grand Bayou study area (Table 2.5), while brackish marsh was most common in the Lake Boudreaux study area. No saline marsh was present in the Lake Boudreaux study area, and <1% was present in the Grand Bayou study area.

The total water increased in both study areas. We divided the total water area by the area of each study area to get a comparable numbers. Figure 2.17 shows that the two study areas

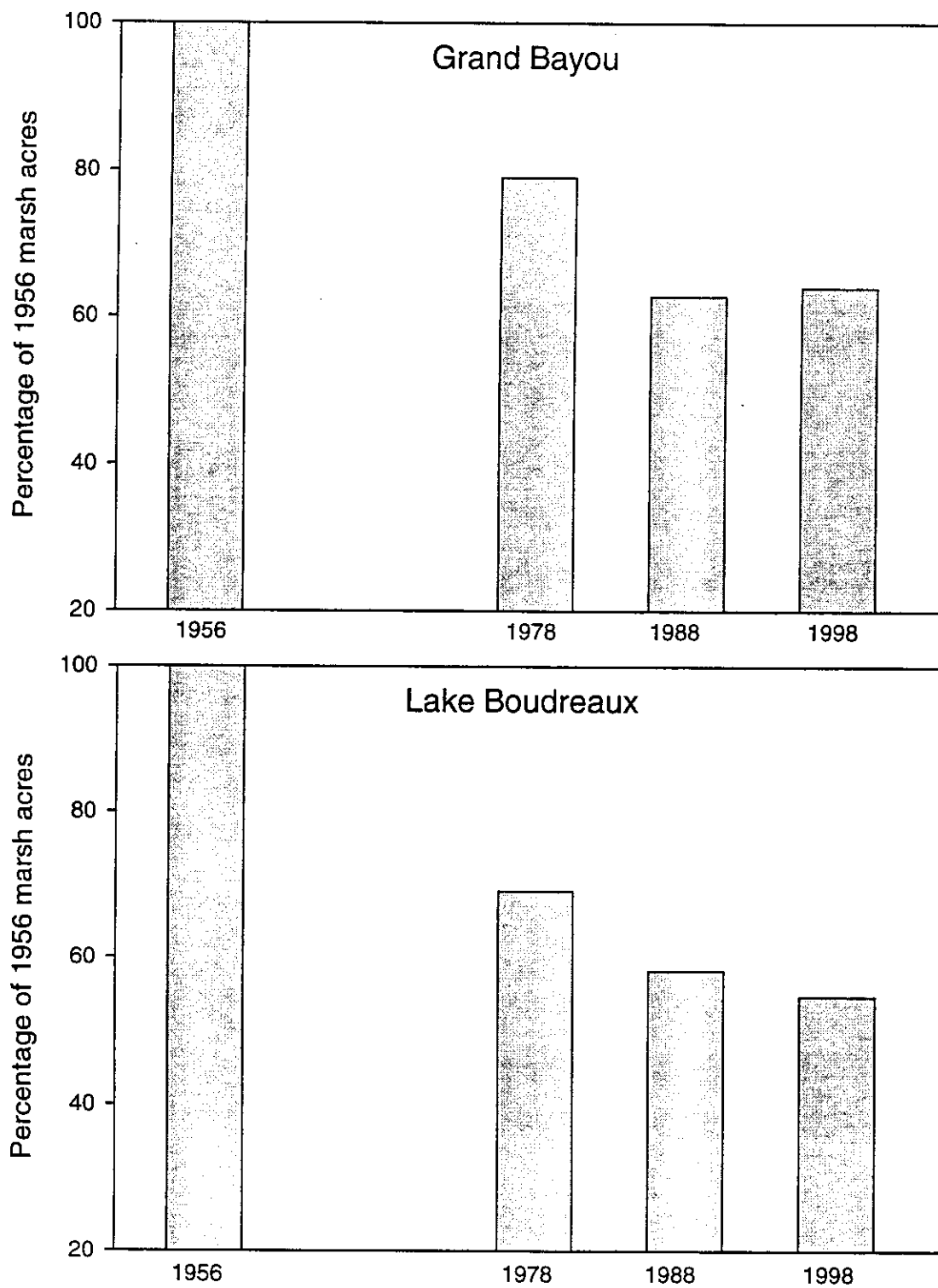


Figure 2.16. Change in percentages of marsh area over time, using 1956 as the baseline, for Grand Bayou and Lake Boudreaux areas.

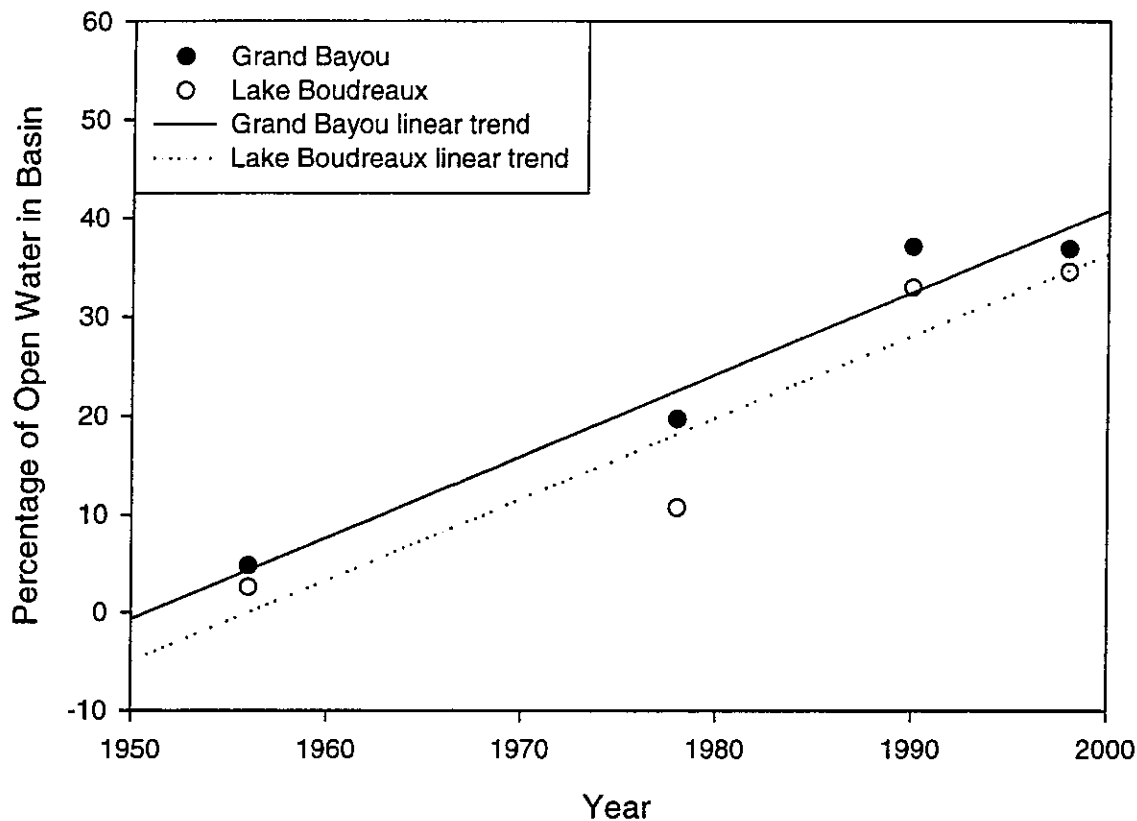


Figure 2.17. Percentage of open water area within the Grand Bayou and Lake Boudreaux study areas.

have similar slopes for increase of water area over time, but the percentage of water in the Grand Bayou study area has always been greater than at Lake Boudreaux.

Changes in the Grand Bayou study area between 1978 and 1988 can be summarized by a decrease in overall marsh area to 30,883 ac, with concomitant decreases in intermediate and brackish marshes (4,672 ac and 3,447 ac, respectively, Table 2.5), while fresh and saline marshes area remained relatively static. Fresh and intermediate marsh areas in the Lake Boudreaux study area decreased from 1978 to 1988 by 2,281 ac and 3,871 ac, respectively, while brackish marsh area increased 3,870 ac. Still no saline marsh was identified in the Lake Boudreaux area.

Between 1988 and 1998, fresh marsh in the Grand Bayou area decreased 5,507 ac. Brackish marsh increased by 5,259 ac, with smaller increases in the intermediate and saline marsh areas of 570 ac and 299 ac, respectively. The Lake Boudreaux area fresh and brackish marshes decreased in area by 294 ac and 778 ac, while intermediate marsh area remained relatively stable. Saline marsh was first noted in 1998 in the Lake Boudreaux area, accounting for 282 ac.

To update the study areas to the more present conditions; we mapped the 1998 imagery using 2 indicators of “health”—percentage of water in the marsh and configuration of water bodies in the marsh. These indicators better identify the level of degradation of the marsh than does straight land/water delineation. Classes 1, 2, 3, 4, 5 and 6 represent differing amounts of water within the marsh from solid (<5% water) to marsh within water (60%-80% water). Figure 2.8 presents the classes by marsh type for each area. Class 4, with 25%-40% open water, accounted for approximately 25% of all marsh types in both areas, except for the polyhaline and fresh marshes in the Grand Bayou area, where it covered less area. Lake Boudreaux consistently had the largest percentage of each of its marsh type (39% in oligohaline marsh, 41% each in mesohaline and fresh, and 74% in saline) in class 5, representing 40%-60% open water within the marsh. The lower salinity fresh and oligohaline marshes in the Grand Bayou area had more marsh in class 3 (10%-25% open water), accounting for 37% and 47%, respectively. The higher salinity marshes had more class 5 marshes, with 40%-60% open water (48% in mesohaline, 79%, saline). The Grand Bayou study area depicts less degraded lower salinity marshes than does the Lake Boudreaux study area. Both study areas have similar class distributions in the mesohaline marsh. (It should be noted here that the polyhaline marshes accounted for very small areas within both study areas.) In the Grand Bayou study area, polyhaline marsh has representation in classes 2-5, while polyhaline marsh within the Lake Boudreaux area is more degraded, with representation only in classes 4, 5, and 6. The class indicator suggests that Grand Bayou area has less degraded fresh, oligohaline, and polyhaline marshes than does Lake Boudreaux.

Configurations “a”, “b”, and “c” represent the shape, size and arrangement of water bodies within the marsh. Only classes 2 through 5 have identifiers, with classes 1 and 6 representing the extremes within the classification system. Figure 2.10 plots the percentages of the categories by marsh type for Grand Bayou and Lake Boudreaux. We included the marsh present in classes 1 and 6 to account for all of the marsh in each marsh type.

Figure 2.10 shows that over 55% of both the fresh and oligohaline marshes in the Grand Bayou area are configuration “a”. The fresh marsh in the Lake Boudreaux area had just less than 50% of the marsh area in configuration “a”. In both areas “b” accounted for 10%-15% of each marsh type except polyhaline, where it accounted for <10%. A higher percentage of category “c” was present for each marsh type in the Lake Boudreaux area than in the Grand Bayou area. Figure 2.8 illustrates that classes 1 and 6 accounted for <7% of each marsh type in both basins. With more category “c” and less category “a” in the Lake Boudreaux study area than in the Grand Bayou area, the category indicator implies that the Lake Boudreaux study area is the more degraded of the two areas.

### Summary

- Both study areas have undergone much degradation between 1956 and 1998. Overall marsh area in the Grand Bayou study area has decreased from approximately 49,286 ac to 31,504 ac. Lake Boudreaux study area marshes decreased from approximately 20,894 ac to approximately 11,420 ac.
- The influence of salinity between 1956 and 1978 is apparent in both study areas, with a decrease in fresh marsh to approximately 25% of each area.
- Both study areas have marshes that were severely degraded by 1998.
- Changes in the Grand Bayou study area between 1978 and 1988 can be summarized by a decrease in overall marsh area, with a concomitant decrease in intermediate and brackish marsh acreages. Fresh and intermediate marshes in the Lake Boudreaux study area decreased, while the brackish and saline marsh areas increased.
- In 1998, fresh marsh covered approximately 14% of both study areas. Brackish marsh covered the largest amount of area (60.4%) in the Grand Bayou study area, while the intermediate and brackish marshes accounted for 83% of the marsh area in the Lake Boudreaux study area. Saline marsh still accounted for <3% of each study area.
- The class indicator suggests that in 1998 the Grand Bayou study area had less degraded fresh, intermediate, and saline marshes than did the Lake Boudreaux study area.

- With more category “c” and less category “a” in the Lake Boudreaux study area than in the Grand Bayou study area, the category indicator implies that the Lake Boudreaux study area is the more degraded of the two study areas.

## **CHAPTER 3: VEGETATION**

### **Introduction**

This section describes the species composition and cover of vegetation found in the Grand Bayou and Lake Boudreaux study areas. The vegetation of coastal marshes in Louisiana has been described both in terms of salinity zones (Chabreck, 1970) and vegetation types (Visser et al., 1998, 1999). We used the previously described vegetation types to describe the vegetation in the two study areas. We compared cover, species diversity, and the relative dominance of the major species with data collected from relatively healthy sites within the same vegetation types elsewhere in the deltaic plain of Louisiana.

### **Methods**

We visited 14 sites in the Lake Boudreaux study area and 17 sites in the Grand Bayou study area. Sites were selected to represent the dominant vegetation types in the study areas. This was determined through preliminary photo-interpretation of 1998 aerial photography as part of the vegetation mapping portion of this study (see Chapter 2), and from information provided by USFWS personnel familiar with the areas. Mr. Ronny Paille (USFWS) is familiar with both study areas and provided information on the marsh vegetation based on observations and data recorded on his previous visits to the region. At each site, we established 5 plots using a random throw of a meter stick. In each 1 x 1m plot the same observer made an ocular estimate of vegetation cover by species to the nearest 5%. From these data we calculated the total cover and number of species within each plot. Relative dominance of each species was calculated as the cover of each species divided by the total cover. Each site was assigned, based on species composition, to one of the vegetation types described by Visser and Sasser (1998). A few sites were in marshes that did not fit any of the described vegetation types and were classified as transition.

### **Results and Discussion**

The 14 sites surveyed in the Lake Boudreaux study area were classified into 6 vegetation types (Table 3.1). The Mesohaline Wiregrass vegetation type was present at the most sites (6).

Table 3.1. Species composition of the sites within the Lake Boudreaux study area.

Vegetation Type	Number of Sites	Species (Relative Dominance)
Fresh Maidencane	1	<i>Panicum hemitomon</i> (63), <i>Hydrocotyle</i> sp. (11), <i>Leersia oryzoides</i> (10), <i>Eleocharis parvula</i> (6), <i>Sagittaria lancifolia</i> (4), <i>Ptilimnium capillaceum</i> (1), <i>Baccharis halimifolia</i> (1), <i>Kosteletzkya virginica</i> (1), <i>Rhynchospora</i> sp (+)
Fresh Bulltongue	1	<i>Sagittaria lancifolia</i> (39), <i>Amaranthus australis</i> (36), <i>Lythrum lineare</i> (14), <i>Echinochloa walteri</i> (6), <i>Scirpus validus</i> (2), <i>Leptochloa fascicularis</i> (1), <i>Polygonum punctatum</i> (1), <i>Eleocharis</i> sp (+)
Oligohaline Bulltongue trans.	1	<i>Sagittaria lancifolia</i> (21), <i>Paspalum vaginatum</i> (17), <i>Amaranthus australis</i> (17), <i>Lythrum lineare</i> (14), <i>Eleocharis</i> sp. (11), <i>Bacopa monieri</i> (8), <i>Spartina patens</i> (6), <i>Leptochloa fascicularis</i> (5), <i>Eleocharis cellulosa</i> (+)
Oligohaline Paspalum trans.	2	<i>Paspalum vaginatum</i> (52), <i>Distichlis spicata</i> (25), <i>Scirpus americanus</i> (20), <i>Sagittaria lancifolia</i> (3), <i>Kosteletzkya virginica</i> (1), <i>Bacopa monieri</i> (+)
Oligohaline Wiregrass	2	<i>Spartina patens</i> (92), <i>Lythrum lineare</i> (5), <i>Typha</i> sp. (2), <i>Kosteletzkya virginica</i> (+)
Mesohaline Wiregrass	6	<i>Spartina patens</i> (87), <i>Distichlis spicata</i> (12), <i>Paspalum vaginatum</i> (+), <i>Scirpus americanus</i> (+)

The 17 sites surveyed in the Grand Bayou study area were classified into 7 vegetation types (Table 3.2). Mesohaline Wiregrass and Mesohaline Mixture were equally frequent in the survey with 5 sites of each. Total cover and species richness are generally lower in the Lake Boudreaux study area than in the Grand Bayou study area (Table 3.3). An exception is the Oligohaline Wiregrass sites. The only Oligohaline Wiregrass site surveyed in the Grand Bayou study area (site E1) had very low total cover (52%). The two Oligohaline Wiregrass sites sampled in the Lake Boudreaux study area (sites BE4 and BE5) had slightly higher total cover (84%) than the Oligohaline Wiregrass site in the Grand Bayou study area, however this cover is still relatively low for a healthy marsh of this type.

Table 3.2. Species composition of the sites within the Grand Bayou study area.

Vegetation Type	Number of Sites	Species Composition , (Relative Dominance)
Fresh Maidencane	2	<i>Panicum hemitomon</i> (64), <i>Thelypteris palustris</i> (19), <i>Decodon verticillatus</i> (7), <i>Eleocharis</i> sp. (3), <i>Triadenum virginicum</i> (3), <i>Hydrocotyle</i> sp. (2), <i>Rhynchospora</i> sp. (2), <i>Boehmeria cylindrica</i> (1), <i>Cyperus</i> sp. (+), <i>Eupatorium capillifolium</i> (+), <i>Polygonum sagittatum</i> (+), <i>Rhynchospora</i> sp. (+), <i>Solidago sempervirens</i> (+)
Fresh Spikerush	1	<i>Hydrocotyle</i> sp. (26), <i>Bacopa monnieri</i> (26), <i>Eleocharis baldwinii</i> (13), <i>Scirpus americanus</i> (13), <i>Phyla lanceolata</i> (10), <i>Paspalum vaginatum</i> (3), <i>Ptilimnium capillaceum</i> (3), <i>Setaria geniculata</i> (3), <i>Solidago sempervirens</i> (3)
Fresh Bulltongue	2	<i>Sagittaria lancifolia</i> (68), <i>Eleocharis</i> sp. (13), <i>Phyla lanceolata</i> (7), <i>Eupatorium capillifolium</i> (5), <i>Echinochloa walteri</i> (4), <i>Lythrum lineare</i> (2), <i>Hydrocotyle</i> sp. (1), <i>Solidago sempervirens</i> (1), <i>Paspalum vaginatum</i> (+), <i>Amaranthus australis</i> (+), Unknown grass (+)
Oligohaline Paspalum trans.	1	<i>Amaranthus australis</i> (84), <i>Paspalum vaginatum</i> (8), <i>Echinochloa walteri</i> (4), <i>Ptilimnium capillaceum</i> (2), <i>Scirpus validus</i> (2), <i>Cyperus</i> sp (1)
Oligohaline Wiregrass	1	<i>Spartina patens</i> (79), <i>Iva frutescens</i> (15), <i>Pluchea camphorata</i> (5), <i>Amaranthus australis</i> (1), <i>Lythrum lineare</i> (1), <i>Ptilimnium capillaceum</i> (+)
Mesohaline Wiregrass	5	<i>Spartina patens</i> (62), <i>Distichlis spicata</i> (24), <i>Spartina alterniflora</i> (9), <i>Paspalum vaginatum</i> (5)
Mesohaline Mixture	5	<i>Distichlis spicata</i> (58) , <i>Spartina patens</i> (36), <i>Spartina alterniflora</i> (6), <i>Aster tenuifolius</i> (+)

The Fresh Maidencane marshes in both study areas had lower species richness (Table 3.3) than the average healthy Fresh Maidencane marsh (Table 3.4). However, the species richness of the studied sites fall within the range of species richness in "healthy" Fresh Maidencane marshes (Table 3.4). The relative dominance of *Panicum hemitomon* is lower (64; Table 3.3) in the studied sites than the relative dominance of this species in "healthy" Fresh

Table 3.3. Total cover and species richness in the two study areas.

Vegetation Type	Grand Bayou Study Area			Lake Boudreaux Study Area		
	Sites #	Cover %	Richness spec./m <sup>2</sup>	Sites #	Cover %	Richness spec./m <sup>2</sup>
Fresh Maidencane	2	106 (93–125)	5.7 (4–7)	1	98 (80–123)	4.2 (3–5)
Fresh Spikerush.	1	155 (155–156)	9.2 (9–10)			
Fresh Bulltongue	2	108 (100–122)	4.9 (3–7)	1	103 (90–140)	5.2 (4–7)
Oligohaline Bulltongue trans.				1	117 (100–135)	6.8 (5–8)
Oligohaline Paspalum trans.	1	102 (95–107)	4.0 (3–5)	2	89 (70–100)	2.6 (2–4)
Oligohaline Wiregrass	1	52 (40–62)	2.6 (2–3)	2	84 (60–100)	1.8 (1–3)
Mesohaline Wiregrass	5	100 (95–110)	2.8 (2–4)	6	73 (35–100)	1.6 (1–3)
Mesohaline Mixture	5	102 (100–120)	2.7 (2–4)			

Maidencane marshes (75; Table 3.4). The common occurrence of the fern *Thelypteris palustris* in the Fresh Maidencane marsh in the Grand Bayou study area and its absence in the Lake Boudreaux study area is significant, because we generally associate this species with “healthy” Fresh Maidencane marshes.

Table 3.4. Species composition of different vegetation types in selected "healthy" Louisiana marshes.

Vegetation type	Description	Site†	Data Source
Fresh Maidencane	Dominated by <i>Panicum hemitomon</i> (RD‡ = 76). All other species had RD values smaller than 10. The average number of species in a 0.25 m² plot ranged from 3.6 to 12.4. The site with the lowest number of species was the only site that did not float. Dominated by <i>Panicum hemitomon</i> (RD = 75). All other species had RD values smaller than 10. The average number of species in a 0.25 m² plot was 11.5 and ranged from 1 to 32.	BT  LB	Sasser et al. 1994  Visser et al. 1996
Fresh Bulltongue	Mixture of <i>Sagittaria lancifolia</i> and <i>Panicum hemitomon</i> . Relative dominance of <i>Sagittaria lancifolia</i> decreased during the growing season (RD = 31 in June and 18 in September), while the dominance of <i>Panicum hemitomon</i> increased (RD = 34 in June and 42 in September) Fall measured RD are as follows: <i>Panicum hemitomon</i> 39, <i>Sagittaria lancifolia</i> 11, <i>Leersia oryzoides</i> 21, no other species had RD values greater than 10. The average number of species in a 0.25 m² plot ranged from 4.8 to 7.6. Dominated by <i>Eleocharis baldwinii</i> in the spring (RD = 74) and overtopped by other species in the fall (RD = 24). Fall overtopping species include <i>Bidens laevis</i> (RD = 29). The average number of species in a 0.10 m² plot ranged from 5.4 to 9.8. Fall measured RD are as follows: <i>Sacciolepis striata</i> 29, <i>Eleocharis baldwinii</i> 11, <i>Aeschynomene indica</i> 10, no other species had RD values greater than 9.	KV  BT  TU BT	Sasser et al. 1995  Sasser et al. 1994 Sasser et al. 1995 Sasser et al. 1994
Fresh Spikerush	Co-dominated by <i>Sagittaria lancifolia</i> (RD = 22) and <i>Eleocharis</i> spp. (RD = 22), other frequently occurring species include <i>Althernanthera philoxeroides</i> 16, <i>Aster subulatus</i> 14, and <i>Leptochloa fascicularis</i> 11, no other species had RD values greater than 10. The average number of species in a 0.25 m² plot was 13.1 and ranged from 5 to 23. Dominated by <i>Spartina patens</i> (RD = 27), other frequently occurring species include <i>Eleocharis rostellata</i> 23 and <i>Scirpus americanus</i> 17. The average number of species in a 0.10 m² plot ranged from 8.4 to 9.6.	CL  BT	Evers et al. 1998  Sasser et al. 1994
Oligohaline Bulltongue	Dominated by <i>Spartina patens</i> (RD = 79), with <i>Distichlis spicata</i> as another frequently occurring species (RD = 13).	MB	Nyman et al. 1995
Oligohaline Wiregrass	A mixture of <i>Spartina patens</i> (RD = 48), <i>Spartina alterniflora</i> (RD = 38), and <i>Distichlis spicata</i> (RD = 14)	MB	Nyman et al. 1995
Mesohaline Wiregrass	A mixture of <i>Spartina patens</i> (RD = 9), <i>Spartina alterniflora</i> (RD = 78), and <i>Distichlis spicata</i> (RD = 13). The average number of species in a 0.1 m² plot was 3.0 and ranged from 1 to 6.	TW	Visser et al. 1996
Mesohaline Mixture	Dominated by <i>Spartina alterniflora</i> (RD = 90). Dominated by <i>Spartina alterniflora</i> (RD = 100). The average number of species in a 0.25 m² plot was 1.0 and ranged from 1 to 2.	TB AL	Turner et al. 1998 Visser et al. 1996

† Sites: BT = Barataria and Terrebonne, KV = Kent and Victor Bayou, LB = Lake Boeuf, MB = Madison Bay, TU = Turtle Bayou, TW = Tidewater Canal

‡ RD = Relative Dominance: the percentage of the total live aboveground biomass contributed by this species.



## **CHAPTER 4: HYDROLOGIC CHARACTERIZATION**

### **Introduction**

The purpose of this chapter is to summarize the overall hydrologic characteristics (precipitation, water levels, and salinity) of the Terrebonne Basin with emphasis (whenever possible) on the Grand Bayou Blue and Lake Boudreaux study areas. The characterization is based on the analysis of the available historical data sets for the-basin, since no new hydrologic data was collected for this study. The broad goal was to estimate the probable impacts of freshwater diversions into the area on the system hydrology. This was accomplished through statistical analysis of the available time series salinity, rainfall, Atchafalaya River stage, and water level data. A water budget was also developed for the system to quantify the magnitudes of the freshwater inputs into the system, and the probable effects of management activities.

### **Methods**

The data used are from time series data sets that were readily available in a computer compatible format (usually an "ASCII" data file). The data came from the following sources:

1. Hourly salinity data from a recording gauge at Cocodrie, maintained by the Louisiana Department of Wildlife and Fisheries (LDWF). The gauge location is indicated in Figure 4.1.
2. Hourly water level and salinity data from recording gauges deployed by the United States Geological Survey (USGS) in the Grand Bayou Watershed. The gauge locations are indicated in Figure 4.1.
3. Hourly water level data from a recording gauge deployed by the Coastal Ecology Institute (CEI) at Louisiana State University (LSU) in the Grand Bayou Watershed. The gauge location is indicated in Figure 4.1.
4. Water level data from the National Ocean Survey (NOS) of the National Oceanic and Atmospheric Administration (NOAA). The gauge location is indicated in Figure 4.1.
5. Daily water level and salinity data from sites sampled by the United States Corps of Engineers (COE). The station locations are indicated in Figure 4.1.

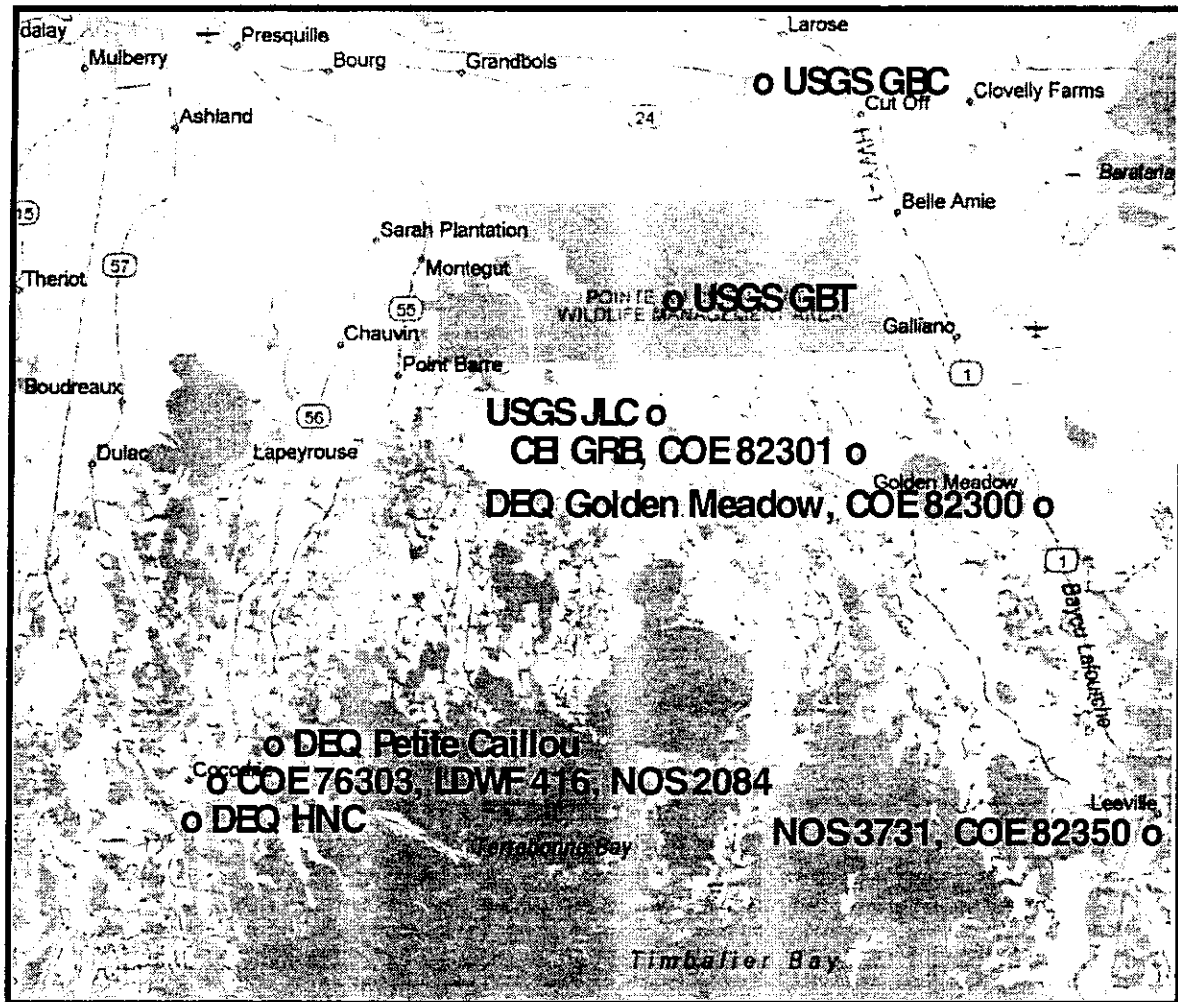


Figure 4.1. Map of the Terrebonne basin showing the locations of recording instruments (water level and/or salinity) deployed by the United States Geologic Survey (USGS), the Louisiana Department of Wildlife and Fisheries (LDWF), the National Ocean Survey (NOS), and the Coastal Ecology Institute at Louisiana State University (CEI). The locations of the Army Corps of Engineers (COE) and the Louisiana Department of Environmental Quality (DEQ) discrete sample locations are also shown.

6. Discrete salinity data from a study conducted in the Grand Bayou basin by Egger et al. (1961). The station locations are indicated in Figure 4.2.
7. Discrete salinity data from the Louisiana Cooperative Inventory and Study (Barrett 1961) in the Terrebonne Basin. The station locations are indicated in Figure 4.3.



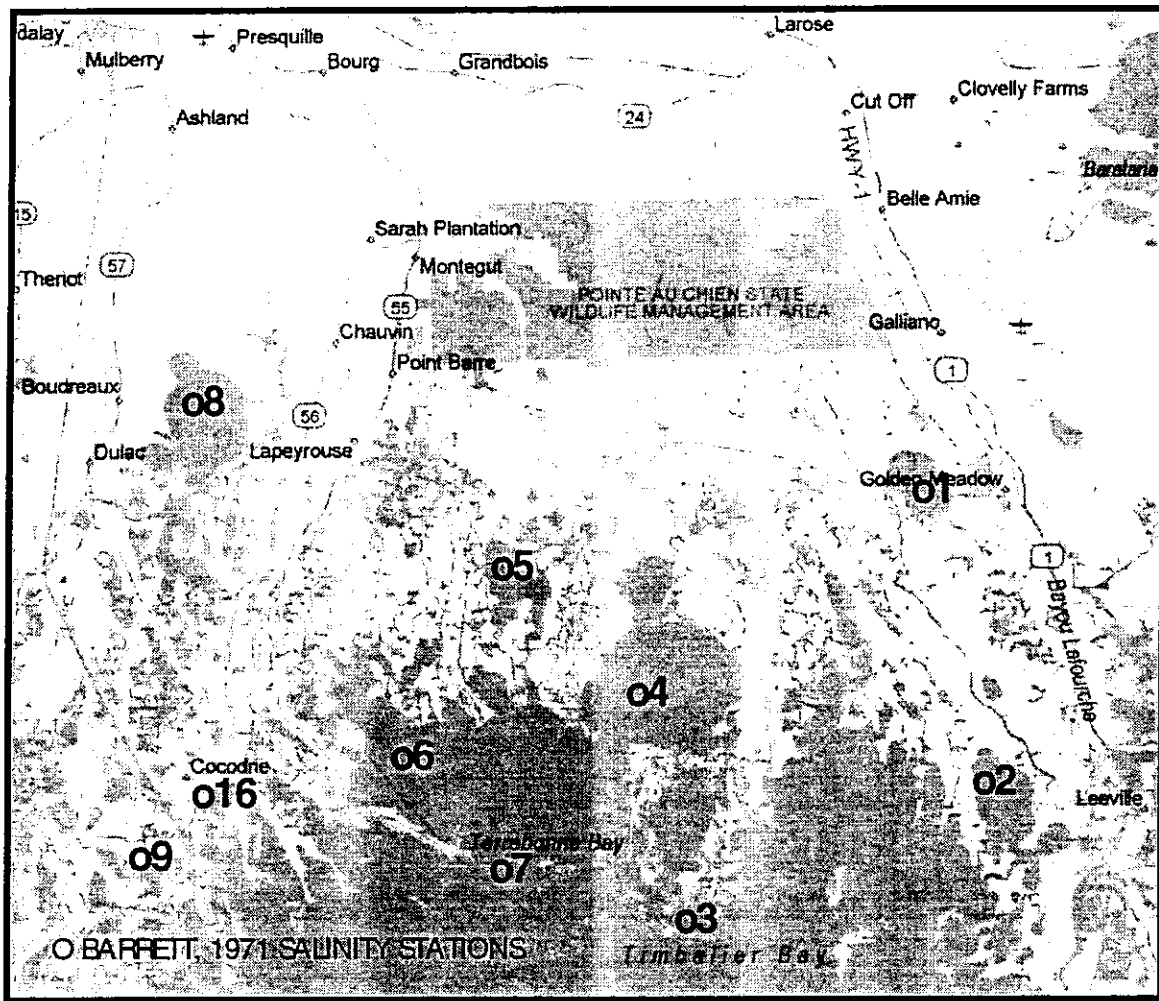


Figure 4.3. Map of the Terrebonne basin showing the locations of discrete salinity stations sampled by Barrett (1971).

The data files were transferred to a desktop computer for analysis using "Statistical Analysis System" (SAS 1990 a, b, c, d, e) and Microsoft EXCEL (Microsoft Corporation 1994).

The analysis of these data consisted of:

1. Obtaining updated data files.
2. Time series plots of the data.
3. Water level trends and patterns.
4. Salinity patterns in the study areas.
5. Water renewal times.

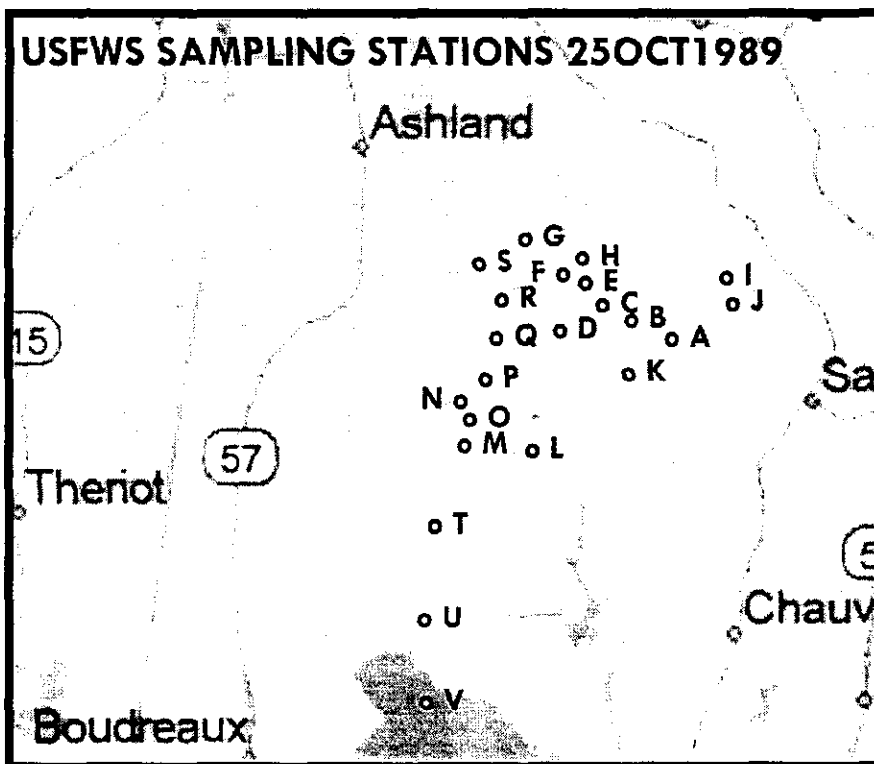
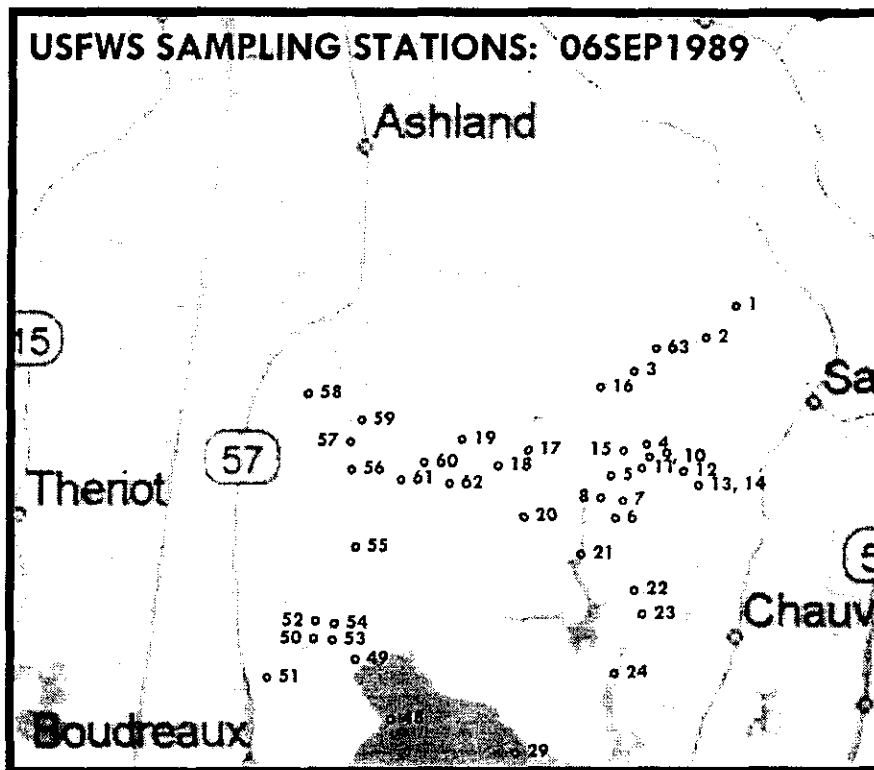


Figure 4.4. Map of the Lake Boudreaux study area showing the locations of discrete salinity stations sampled by the USFWS in 1989.

Wax et al. (1978) produced a water budget for the Barataria Estuarine System (BES) based upon climatic conditions to estimate periods of surplus and deficit for the BES. They described a surplus in winter and spring when precipitation was high and evapotranspiration was low, and deficits in summer and autumn. Sklar (1983) produced an average annual water budget for the upper portions of the BES based upon data from 1914 through 1978. Sklar's data shows that most of the surplus occurs in winter, with deficits most likely to occur during the summer (June-July). Although the autumn did not show a deficit, the surplus was quite low. Sklar (1983) also noted that deficits (dry-downs) should not be expected to occur regularly, because precipitation is usually greater than evaporation. To create a water budget for the BES by wetland type, Swenson and Turner (1998) modified the basic water budget from Sklar (1983). This approach was also used in this study. The habitat classes for each study area were lumped into the following categories using the data from the Habitat Analysis Chapter:

- A. Water
- B. Fresh (includes forest)
- C. Intermediate
- D. Brackish (includes Brackish and Saline since saline is such a small percentage)
- E. Shrub/Scrub
- F. Other

The 28-year averages (1960-1988) of the precipitation variables (rainfall, evaporation, surplus) were used in the water budget calculation. The runoff was calculated on a monthly basis for each category, then an annual total was calculated.

The total volume of water in the system was estimated by using the area of marsh in each marsh type category (Fresh 1-6, Oligohaline 1-6, Mesohaline 1-6, and Polyhaline 1-6), the area of open water, and the area of canals. An average water depth was assigned to each marsh type category, the open water area, and the canal area. The depths were those depths that would occur when the water is at the level of the marsh surface, but the marsh is not flooded. The total volume was obtained by multiplying the water depth by the marsh type category and summing for the entire system. The total volume was divided by the runoff to obtain the runoff renewal time for the system. The tidal prism was determined using the same procedure, using an estimated tidal amplitude for each marsh type category instead of water depth. The open water

area and canal area was prorated among the marsh type classes depending upon the proportion of the total area represented by the given marsh type class.

## Results and Discussion

### Water Levels

Time series plots of long-term water levels for Grand Isle, Leeville, Catfish Lake, and Houma are presented in Figures 4.5 through 4.8. The results of a regression analysis between water level and elapsed time are shown on each plot. The slope of the regression is the value for relative sea level rise for the given station. The analysis resulted in the following relative sea level rise estimates:

Grand Isle	0.035 ft yr <sup>-1</sup>	(1.06 cm yr <sup>-1</sup> )
Leeville	0.025 ft yr <sup>-1</sup>	(0.77 cm yr <sup>-1</sup> )
Catfish Lake	0.037 ft yr <sup>-1</sup>	(1.28 cm yr <sup>-1</sup> )
Houma	0.049 ft yr <sup>-1</sup>	(1.49 cm yr <sup>-1</sup> )
<b>Average</b>	<b>0.036 ft yr<sup>-1</sup></b>	<b>(1.11 cm yr<sup>-1</sup>)</b>

The two "coastal" stations (Grand Isle and Leeville) have slightly lower values than the more inland stations (Catfish Lake and Houma). This may represent a larger subsidence rate for these stations or may be due to increases in the local water levels. The station in Houma, which has the highest rate, is located in the Houma Navigational Channel not too far from the Intracoastal Waterway (ICWW). The ICWW is influenced by flows from the Atchafalaya River, which move eastward through the ICWW (Chris Swarzenski, USGS, personal communication). An analysis of stage from the Atchafalaya River at Morgan City indicated a sea level rise of 0.046 ft yr<sup>-1</sup> (1.41 cm yr<sup>-1</sup>). Examples of hourly water level data for Cocodrie and Leeville are presented in Figures 4.9 and 4.10, respectively. This data represents the "coastal" endpoint for each of the basins. The water level pattern is typical for coastal Louisiana with tidal forcing of ~ 1 foot (30.5 cm) superimposed upon longer-term fluctuations. These longer-term fluctuations are typically due to meteorological forcing. The data from both locations indicate that the total water level fluctuations (tidal and frontal induced) are on the order of 3.3 feet (1 m). Hourly

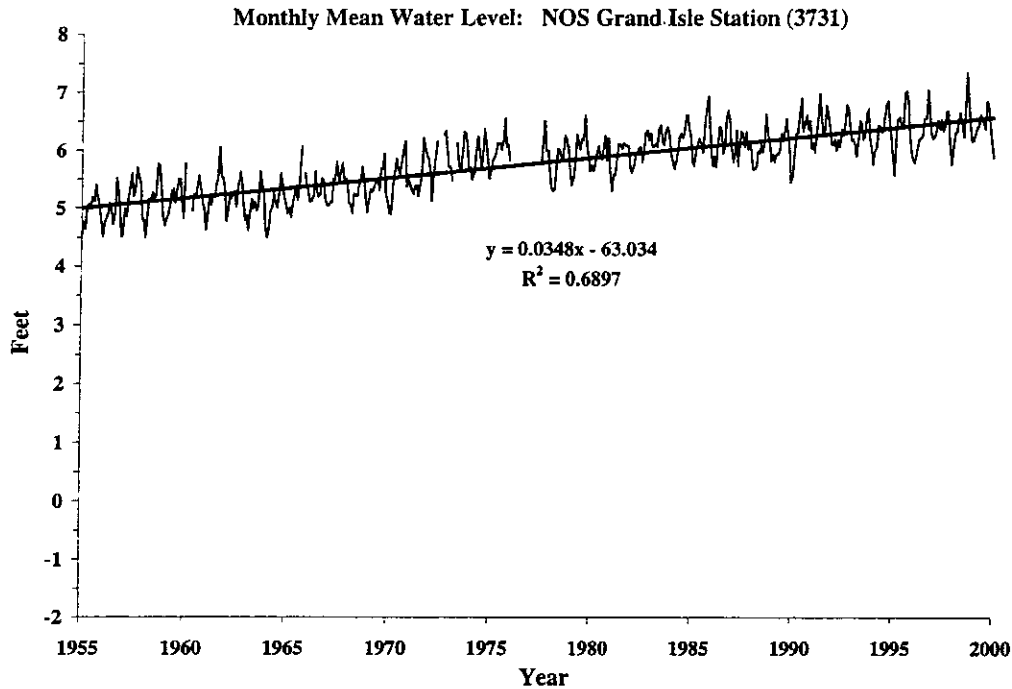


Figure 4.5. Plot of monthly mean water level (computed from hourly observations) from Grand Isle (NOS Station 3731). The long term apparent sea level rise is indicated by the linear fit to the data.

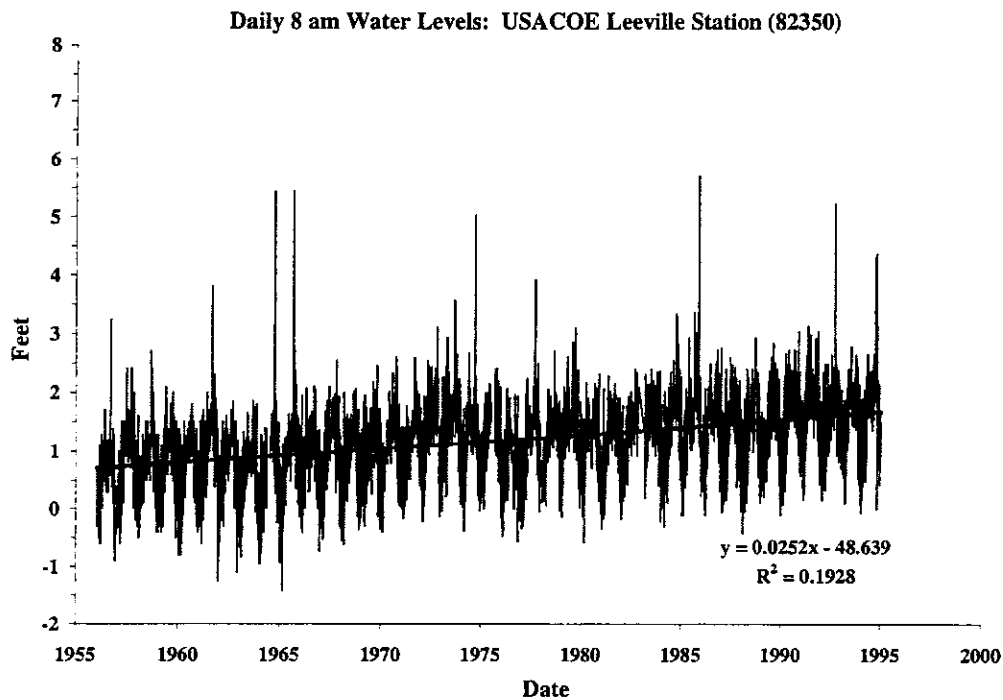


Figure 4.6. Plot of daily 8 am water level from Leeville (COE Station 82350). The long term apparent sea level rise is indicated by the linear fit to the data.

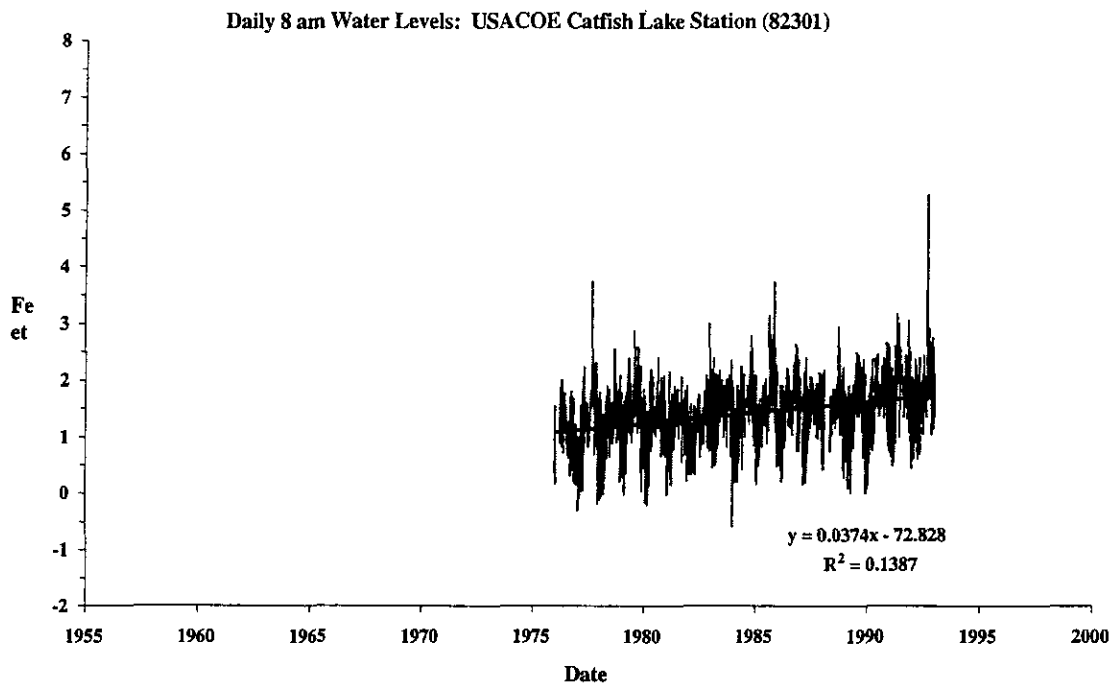


Figure 4.7. Plot of daily 8 am water level from Catfish Lake (COE Station 82301). The long term apparent sea level rise is indicated by the linear fit to the data.

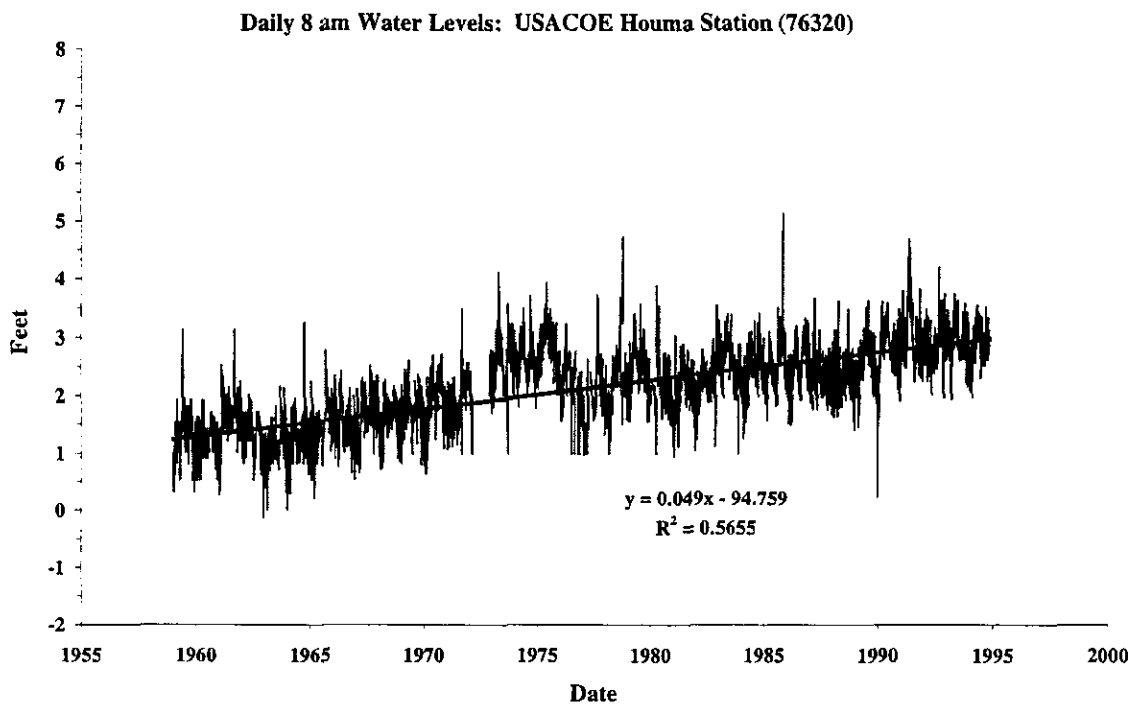


Figure 4.8. Plot of daily 8 am water level from Houma (COE Station 76320). The long term apparent sea level rise is indicated by the linear fit to the data.

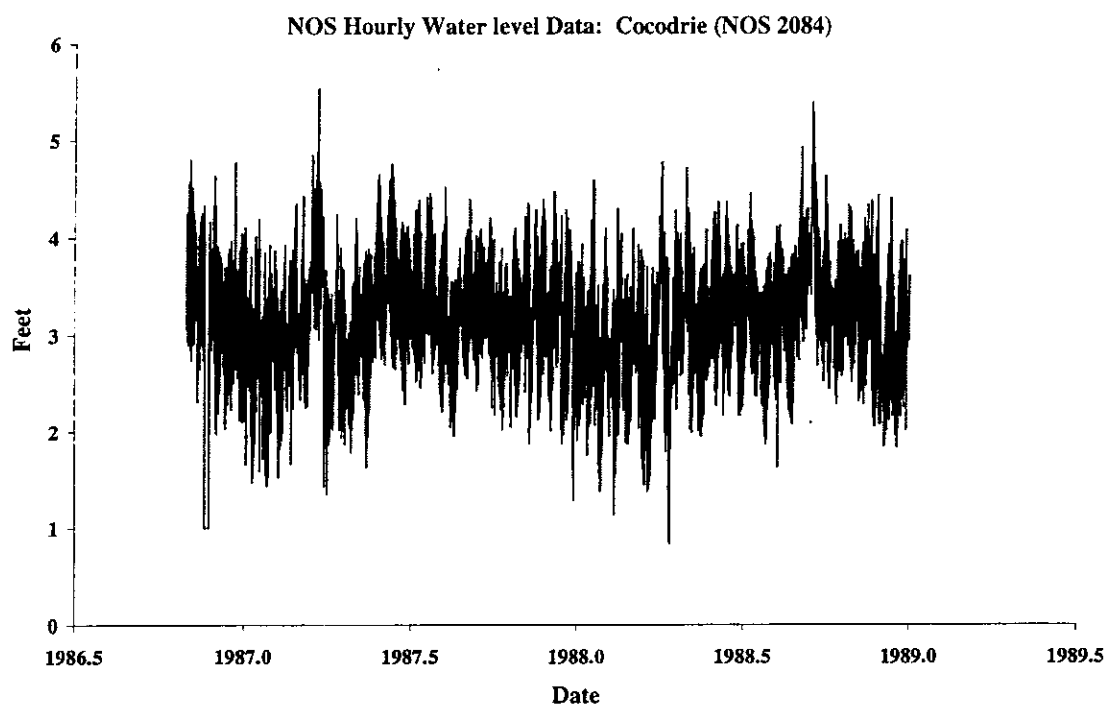


Figure 4.9. Plot of hourly water level from Cocodrie (NOS Station 2084) over the time period from November, 1986 through December, 1989. The values are in feet NGVD.

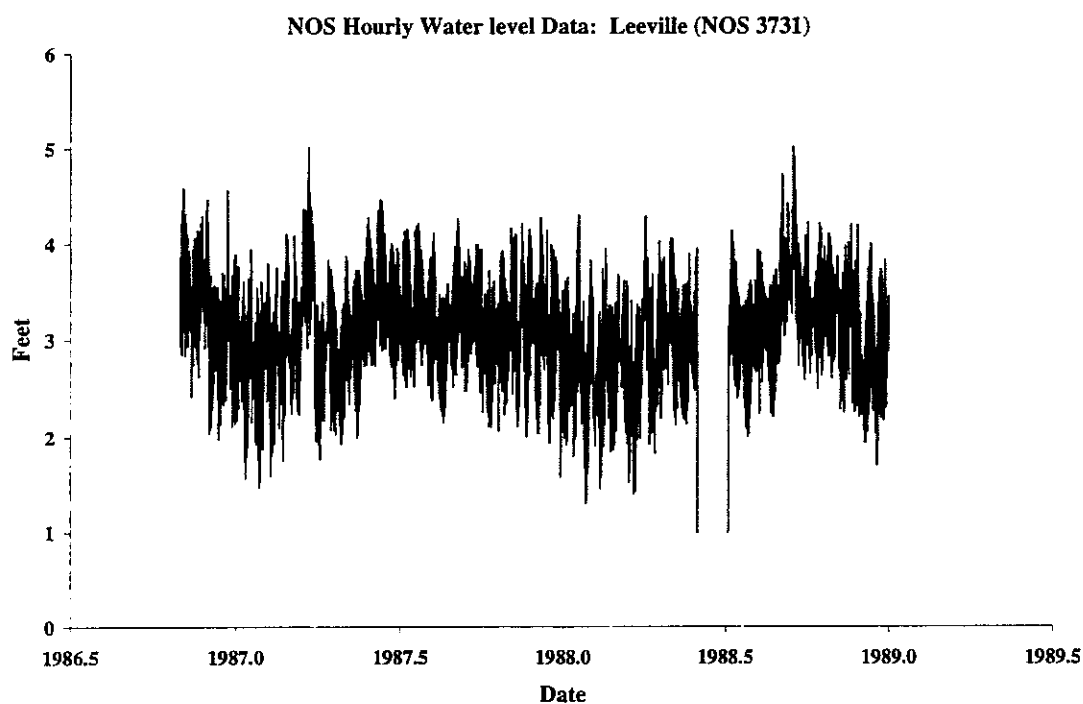


Figure 4.10. Plot of hourly water level from Leeville (NOS Station 3731) over the time period from November, 1986 through December, 1989. The values are in feet NGVD.

water level data for stations deployed by the United States Geological Survey (USGS) and the Coastal Ecology Institute at LSU in the Grand Bayou Study area over the time period from 1995 through 1997 are presented in Figures 4.11 through 4.14. The plots extend from a station in the lower portion of the system (Figure 4.11) to the upper portion of the system (Figure 4.14). The overall pattern is similar at each station; however, a marked decrease in the tidal fluctuations occurs from the lower station to the upper station. Although there is not a similar data set available for the Lake Boudreaux study area, the National Ocean Survey (NOS) has determined co-range (lines of equal tidal range) lines for the Terrebonne Basin. The co-range lines are presented in Figure 4.15. This figure is modified from a draft co-range chart (developed by NOS) supplied to us by Mr. Ronnie Paille of the United States Fish and Wildlife Service. The data indicate that the tidal amplitudes at the southern boundary of the Lake Boudreaux Study area are much lower than the southern boundary of the Grand Bayou Study area (0.3 feet and 0.6 feet, respectively). The actual data from the Grand Bayou Study area at the southern boundary near Catfish Lake (Figure 4.13) indicate tidal amplitudes of ~0.5 feet which agrees with the NOS co-range lines. A second gauge near the southern boundary of the Grand Bayou study area but further west in a major canal shows tidal amplitudes of about 1 foot. This is quite a bit higher than the ~0.6 feet shown on the co-range chart. This difference is due to the presence of this canal that has a direct connection to more southern water bodies where the tidal amplitudes are much higher (1 foot).

### **Salinity**

A summary of the discrete salinity data from stations in the Grand Bayou basin (Figure 4.2) sampled by Egger et al. (1961) is given in Table 4.1. The discrete salinity data from stations in the Terrebonne Basin (Figure 4.3) sampled by Barrett (1971) are presented in Table 4.2. The Egger et al. (1961) data measured salinities of 15-20 for the coastal stations, ~15 ppt for Catfish Lake, 6 to 9 ppt for stations in the center, and 3.8 ppt for a station in the northern portion of the Grand Bayou basin. The Barrett (1971) salinity data showed a mean salinity of 12.2 ppt for Catfish Lake, and a mean salinity of 3.2 ppt for Lake Boudreaux. The salinity for several stations at the coastal endpoints of the Lake Boudreaux and Grand Bayou study areas is

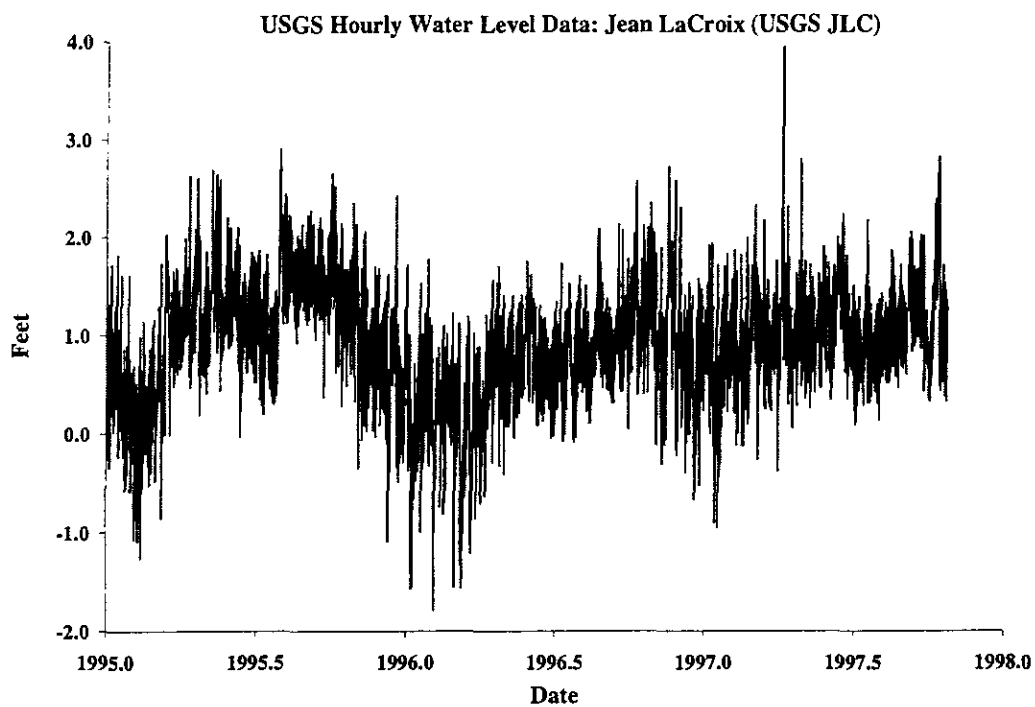


Figure 4.11. Plot of hourly water levels from the USGS station in Bayou Jean Lacroix (USGS JLC) over the time period from January, 1995 through December, 1997.

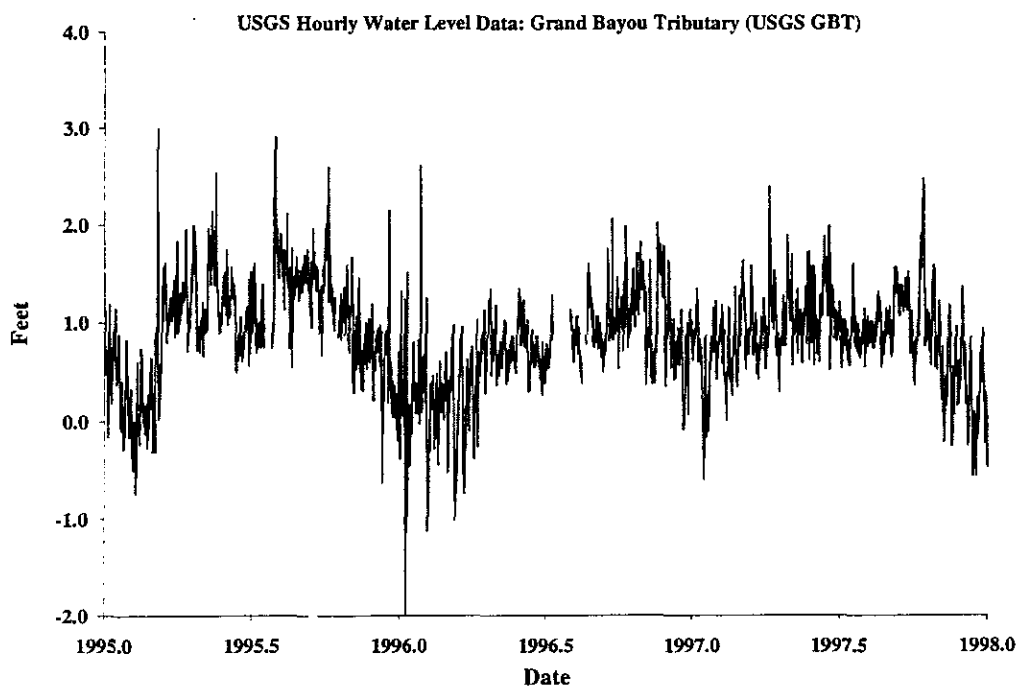


Figure 4.12. Plot of hourly water levels from the USGS station at in Grand Bayou Tributary (USGS GBT) over the time period from January, 1995 through December, 1997.

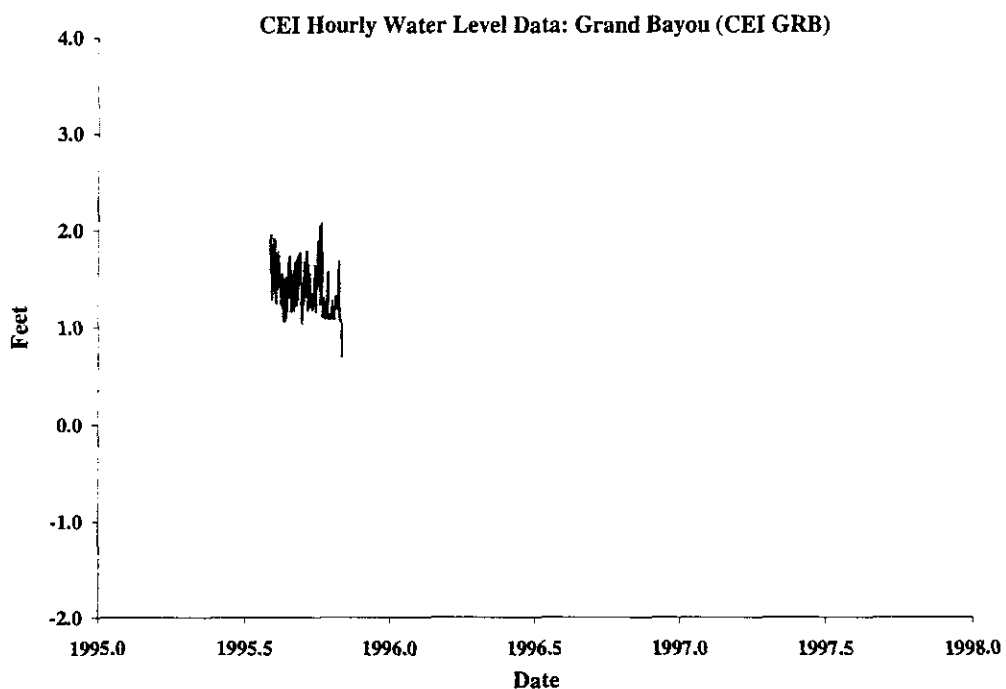


Figure 4.13. Plot of hourly water levels from the LSU CEI station in Grand Bayou (CEI GRB) over the time period from January, 1995 through April, 1995.

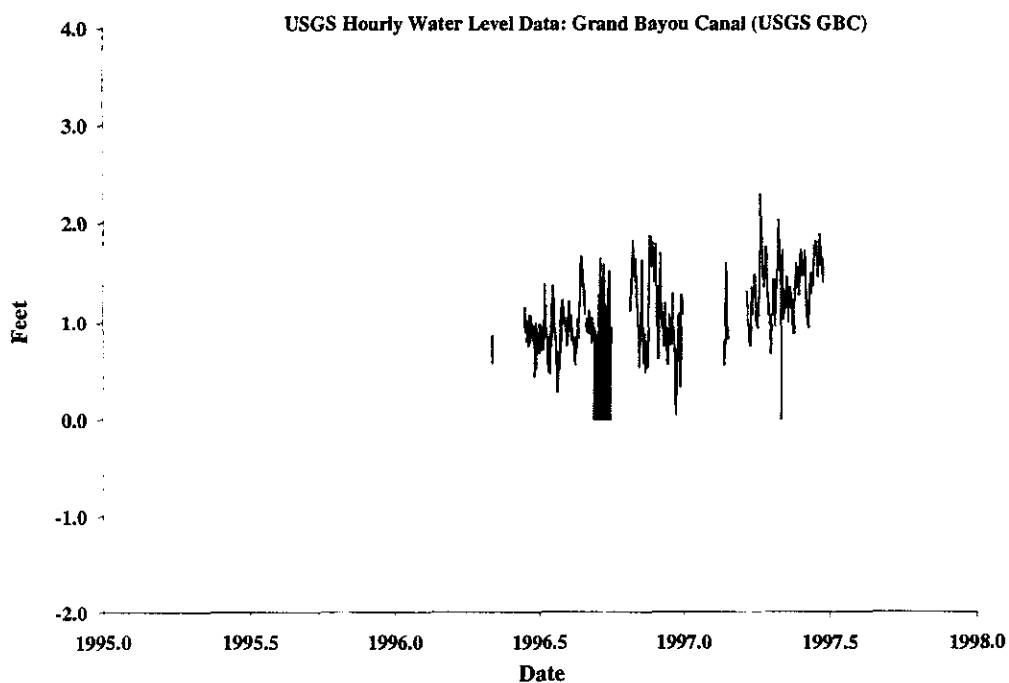


Figure 4.14. Plot of hourly water levels from the USGS station at in Grand Bayou Canal (USGS GBC) over the time period from January, 1995 through December, 1997.

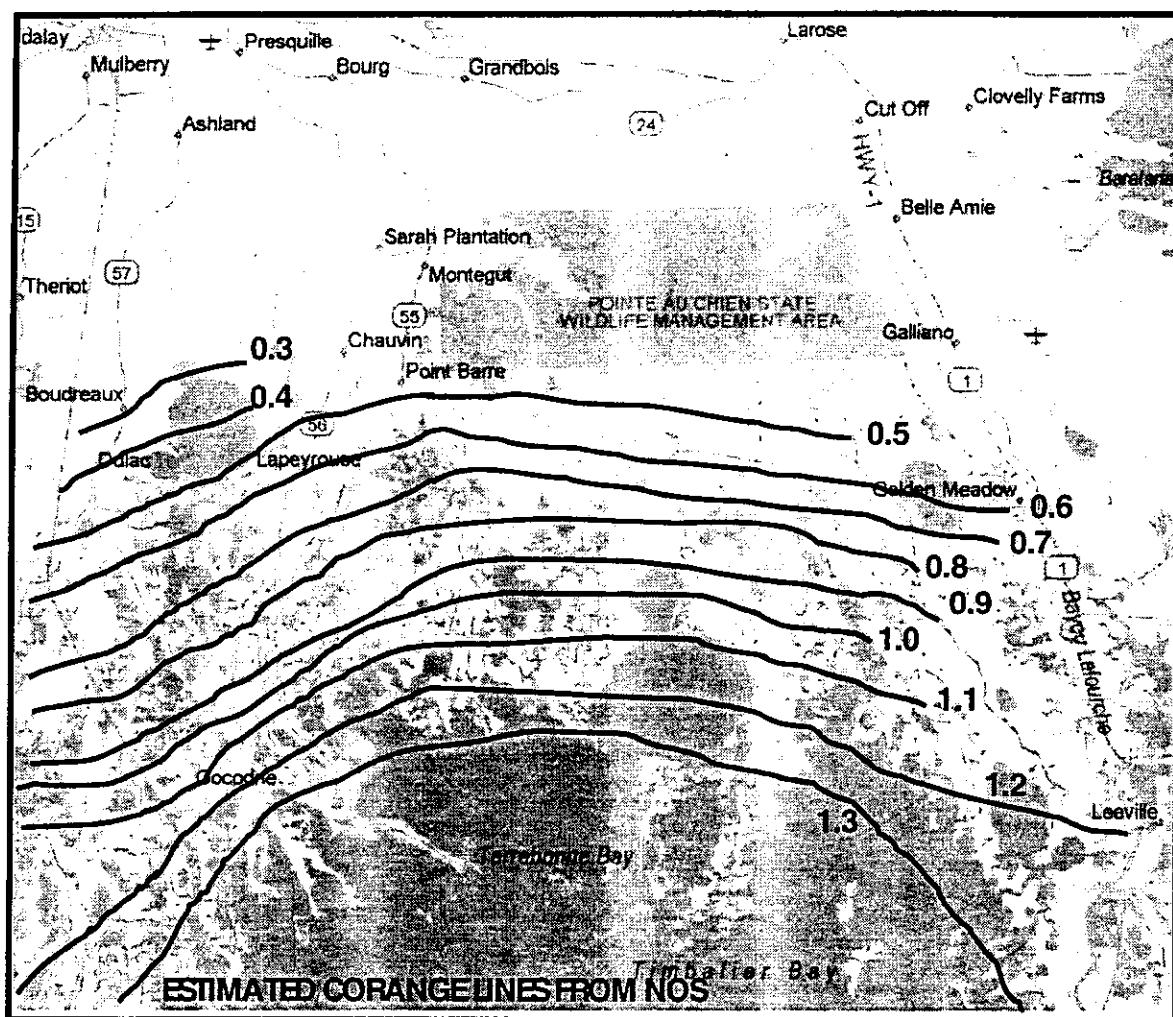


Figure 4.15. Map of the Terrebonne basin showing the estimated corange lines (lines of equal tidal range) in feet. Data adapted from preliminary map supplied by the National Ocean Survey (NOS).

<u>Source</u>	<u>Years of record</u>	<u>Range (ppt)</u>	<u>Mean (ppt)</u>
Barrett (1971)	1968-1969	7.8 to 20.0	12.1
DEQ HNC station	1978-2000	0.4 to 21.6	9.5
LDWF Cocodrie station	1974-1985	0.0 - 27.7	10.2
DEQ Petite Caillou station	1991-2000	0.2 - 6.4	1.4
DEQ Golden Meadow station	1991-2000	0.3 - 12.2	5.7

Table 4.1. Summary of salinity data from stations in the Grand Bayou Blue watershed measured by Eggler et al (1961). The mean is for data from 12/22/54 through 10/15/55. The symbol . indicates no data was collected for the indicated sampling date.

Station	12/22/54	03/19/55	06/25/55	08/02/55	10/15/55	11/26/55	12/29/55
A	17.0	13.6	24.7	9.9	8.1	.	.
B	7.9	3.6	16.5	1.7	1.4	.	.
C	7.7	11.9	21.2	3.2	2.4	.	.
D	10.6	8.9	18.2	6.9	3.0	.	.
E	10.3	9.3	18.7	6.5	3.4	.	.
F	10.3	12.8	22.3	6.3	2.7	6.0	5.7
G	10.3	16.4	23.9	11.4	2.8	5.3	7.7
H	16.3	17.5	26.2	10.1	6.1	5.3	7.7
I	13.1	18.8	25.2	12.4	7.2	6.5	12.7
J	17.1	13.3	24.4	8.5	7.8	10.4	11.0
K	5.9	15.1	21.4	7.8	2.5	3.9	6.4
L	4.1	6.4	17.4	3.5	2.1	.	.
M	11.4	18.8	25.5	11.2	7.5	.	.
N	12.5	18.3	25.4	9.8	10.7	.	.
O	11.0	18.1	25.5	13.2	12.6	14.2	14.5
P	12.1	23.4	29.3	11.7	11.9	14.5	14.4
Q	9.0	16.9	26.4	10.4	8.3	.	.
R	10.3	20.0	27.1	11.6	8.9	13.7	13.7
S	19.5	21.7	27.9	16.4	15.8	20.8	11.4
T	12.5	20.0	25.3	12.4	8.1	.	.
U	13.0	19.7	28.0	13.7	11.3	.	.
V	10.9	18.0	26.1	13.8	6.7	.	.
W	12.1	18.0	25.5	10.2	10.1	16.0	15.1
X	1.7	1.3	14.7	0.8	0.6	1.0	0.7
Station	02/25/56	03/29/56	04/28/56	06/05/56	06/21/56	07/06/56	Mean
A	.	.	.	.	.	.	14.7
B	.	.	.	.	.	.	6.2
C	.	.	.	.	.	.	9.3
D	.	.	.	.	.	.	9.5
E	.	.	.	.	.	.	9.6
F	10.3	7.4	4.0	10.0	3.8	3.0	10.9
G	13.9	12.6	6.4	9.9	4.4	3.5	13.0
H	13.9	12.6	6.4	9.9	4.4	3.5	15.2
I	22.9	12.6	.	.	.	.	15.3
J	19.9	7.9	8.5	13.5	6.4	7.0	14.2
K	11.5	9.5	3.1	10.2	4.4	3.5	10.6
L	.	.	.	.	.	.	6.7
M	.	.	.	.	.	.	14.9
N	.	.	.	.	.	.	15.3
O	26.2	14.5	.	.	.	.	16.1
P	26.0	14.9	.	.	.	.	17.7
Q	.	.	.	.	.	.	14.2
R	24.7	17.4	.	.	.	.	15.6
S	20.5	20.6	.	.	.	.	20.3
T	.	.	.	.	.	.	15.7
U	.	.	.	.	.	.	17.1
V	.	.	.	.	.	.	15.1
W	27.3	11.3	.	.	.	.	15.2
X	1.3	0.3	0.5	0.7	1.3	1.2	3.8

Table 4.2. Summary of salinity data from stations in the Terrebonne Bay area measured by Barrett (1961). The individual sample trip salinity and the mean salinity are listed. The symbol . indicates no data was collected for the indicated sampling date.

			Barrett (1961) Station number									
Year	Month	Day	1	2	3	4	5	6	7	8	9	16
1968	1	9	3.9	7.8	23.2	17.9	16.7	20.4	24.1	1.1	7.6	6.1
1968	2	13	8.8	16.7	20.2	18.3	14.6	18.6	26.8	1.3	13.0	6.6
1968	3	20	12.6	16.6	26.8	20.8	18.8	20.8	27.3	1.8	19.9	8.1
1968	4	29	16.5	20.0	20.3	22.5	21.1	23.0	23.1	4.3	18.6	12.3
1968	5	21	16.5	16.0	24.2	26.8	19.3	21.2	22.9	5.7	7.8	5.6
1968	6	24	15.8	18.5	22.2	22.7	20.8	21.5	22.3	3.6	17.7	6.3
1968	7	15	15.2	16.4	23.5	21.7	18.8	19.8	22.9	4.1	14.9	.
1968	8	27	15.1	16.4	24.3	20.6	16.1	19.5	24.8	3.2	10.4	.
1968	9	24	13.8	12.5	23.4	21.2	18.0	18.3	24.7	3.7	18.3	.
1968	10	24	16.5	19.8	23.2	21.8	19.7	23.6	26.2	6.0	18.8	.
1968	11	19	15.7	19.8	24.7	22.8	19.2	18.2	25.6	5.8	15.8	.
1968	12	17	13.7	17.5	25.1	20.8	17.7	18.1	26.7	5.0	14.5	.
1969	1	21	9.8	16.0	22.1	19.5	16.7	16.0	24.7	3.1	8.0	.
1969	2	25	10.4	16.2	23.2	19.8	15.8	18.3	24.3	2.8	10.6	.
1969	3	26	11.1	13.3	19.8	20.0	17.3	18.3	18.9	2.3	14.5	.
1969	4	21	7.7	12.2	22.6	17.3	10.8	11.7	28.3	1.2	5.2	.
1969	5	26	6.6	10.0	18.7	15.5	13.2	15.0	19.8	1.6	3.2	6.9
1969	6	19	10.4	15.3	18.8	17.2	16.4	16.5	23.3	1.3	14.5	6.9
Mean:			12.2	15.6	22.6	20.4	17.3	18.8	24.3	3.2	13.0	7.4

These data indicate that in general, the salinities at the lower portions of both study areas is around 10-12 ppt, with values of 20 to 30 ppt occasionally occurring. The DEQ stations in Bayou Lafourche (at Golden Meadow) and in Bayou Petite Caillou both have much lower salinities due to the freshwater input into these two bayous. The discrete salinity data collected by the USFWS in the Lake Boudreaux Study area from September 1989 are summarized in Figure 4.16. The data are arranged in two north-south transects and one east-west transect. Transect A goes from Lake Boudreaux, northward along Bayou Chauvin, and Transect B, goes from the east shore of Lake Boudreaux, northward through the canal system on the north-east side of Lake Boudreaux). The east-west transect goes from Bayou Petite Caillou to Bayou Chauvin. The

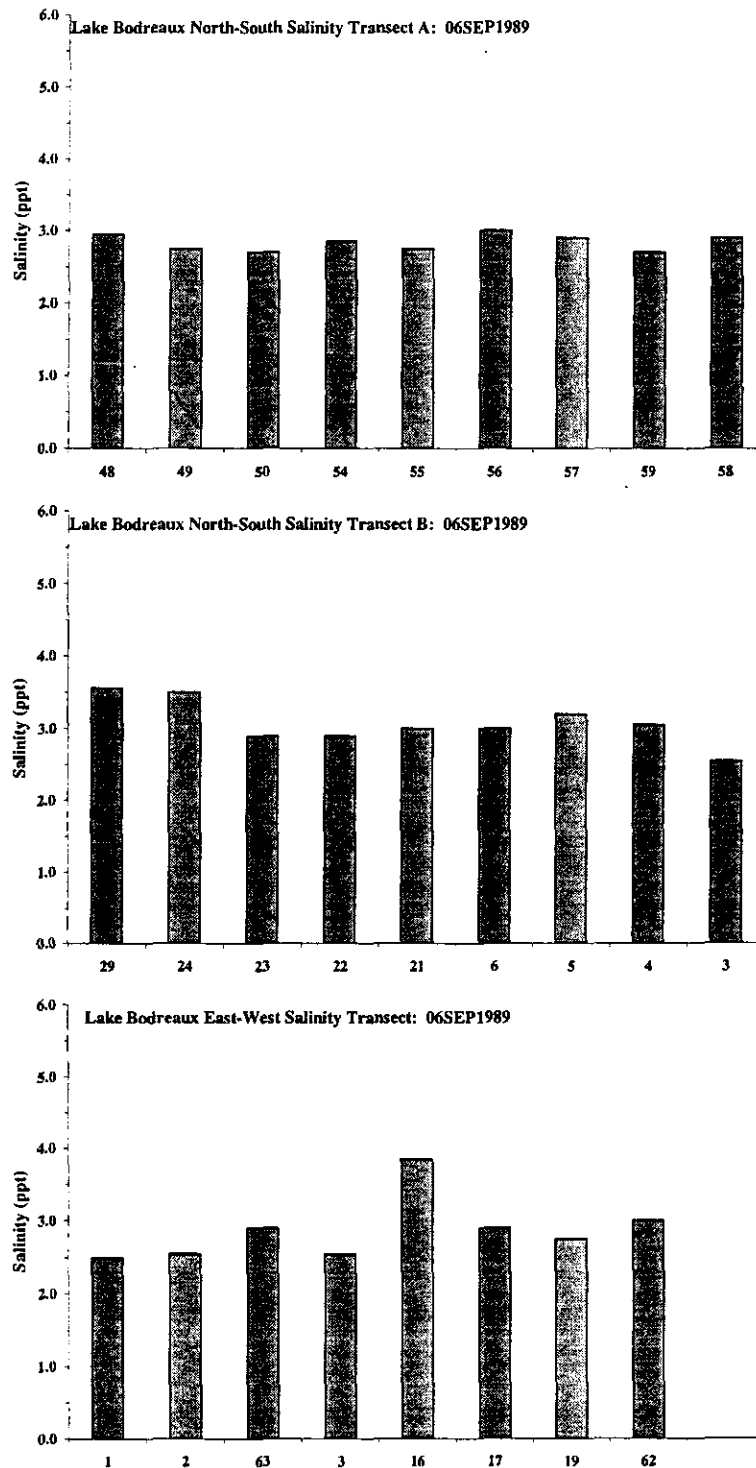


Figure 4.16. Summary of salinity data collected in the Lake Boudreaux study area by the USFWS. The data stations are arranged in two north-south transects from Lake Boudreaux north (top two panels) and an east-west transect from Bayou Petite Caillou to Bayou Chauvin.

discrete salinity data collected by the USFWS in the Lake Boudreaux Study area from October 1989 is summarized in Figure 4.17. The data are arranged in one north-south transect and one east-west transect. The north-south transect goes from Lake Boudreaux, northward along Bayou Chauvin, and the east-west transect goes from Bayou Petite Caillou to Bayou Chauvin. The data from September show a well-mixed system with salinities of 2.5-4.0 ppt at all stations. The October data shows a system with a fairly large (~4.0 ppt) north-south salinity gradient. There is also evidence in the October data of a smaller (~1.0 ppt) east-west salinity gradient. This could be from more saline water entering the system through the canal system and broken marshes in the north-east part of the study area.

Hourly salinity data for the stations deployed by the United States Geological Survey (USGS) over the time period from 1995 through 1997 are presented in Figures 4.18 through 4.20. As was the case with the water level, the overall pattern is similar at each station with a decrease in salinity from the lower station to the upper station. The salinities in the canal at the southern boundary (Figure 4.15) exhibit a great deal of tidal fluctuations. The salinity is around 15 ppt although it may go as high as 25 ppt or as low as 2 to 3 ppt. The salinities further up in the system (Figure 4.19) have a lot less tidal influence. The salinity is around 10 ppt although it may go as high as 20 ppt or as low as ~5 ppt (the values of 0.0 appear to be erroneous). The salinity in the northern portion of the system (Figure 4.20) has minor fluctuations and was less than 3.0 ppt over the entire time period. This station was located in a canal which did have a connection to the Intracoastal Waterway.

### **Water Budget**

The water budget summary for both study areas is presented in Table 4.3. The table presents the rainfall generated surplus for each month for each of the marsh type categories and the total surplus for all categories combined. The results yield a mean rainfall generated surplus (total of all categories) of 128.7 cfs (3.64 m<sup>3</sup> s<sup>-1</sup>) for the Grand Bayou Study area and 59.7 (1.69 m<sup>3</sup> s<sup>-1</sup>) cfs for the Lake Boudreaux Study area. The maximum surplus occurs in December, deficits occur from May through July, and the surplus for August is very small.

The water volume and renewal times for the Grand Bayou Study area and the Lake Boudreaux study area are presented in Tables 4.4 and 4.5 respectively. The calculations yielded a runoff renewal time of 182 days for the Grand Bayou Study area and 157 days for the Lake

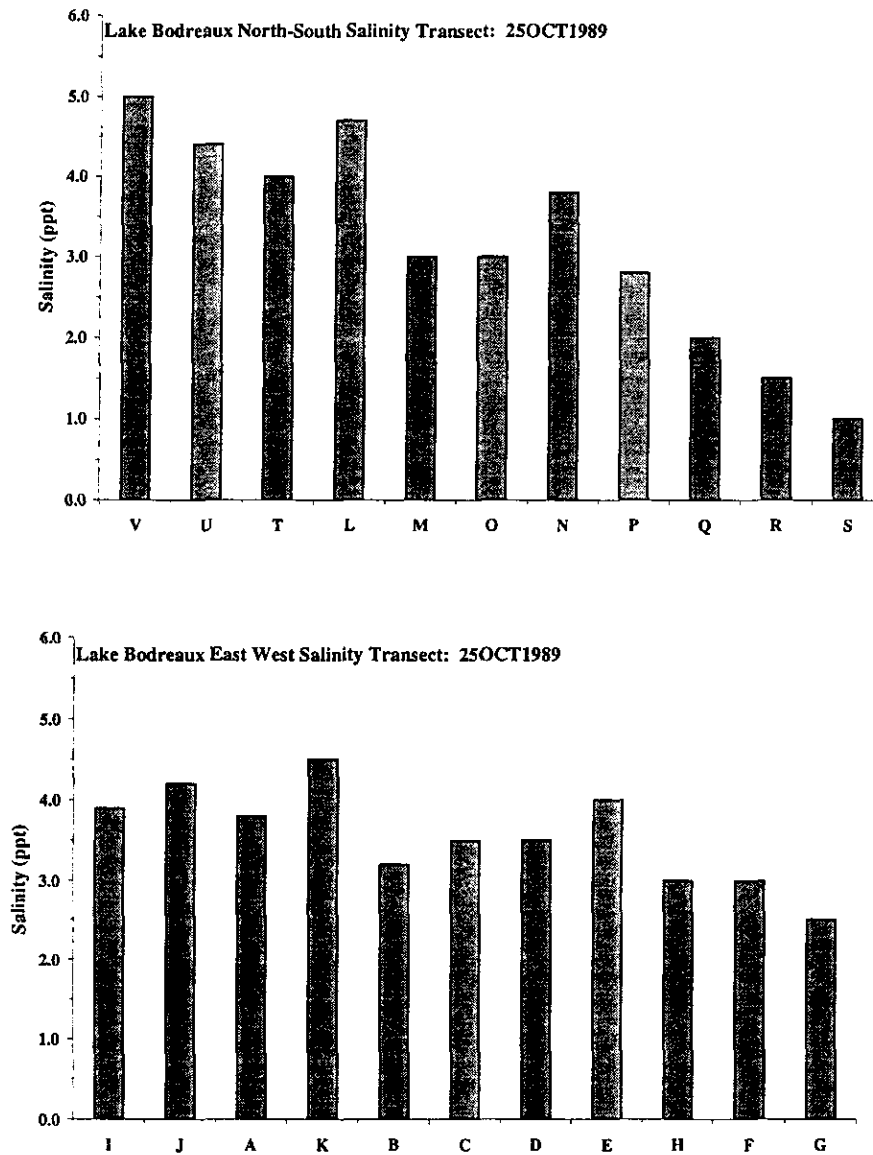


Figure 4.17. Summary of salinity data collected in the Lake Boudreaux study area by the USFWS. The data stations are arranged in a north-south transects in Bayou Chauvin (top panel) and an east-west transect from Bayou Petite Caillou to Bayou Chauvin.

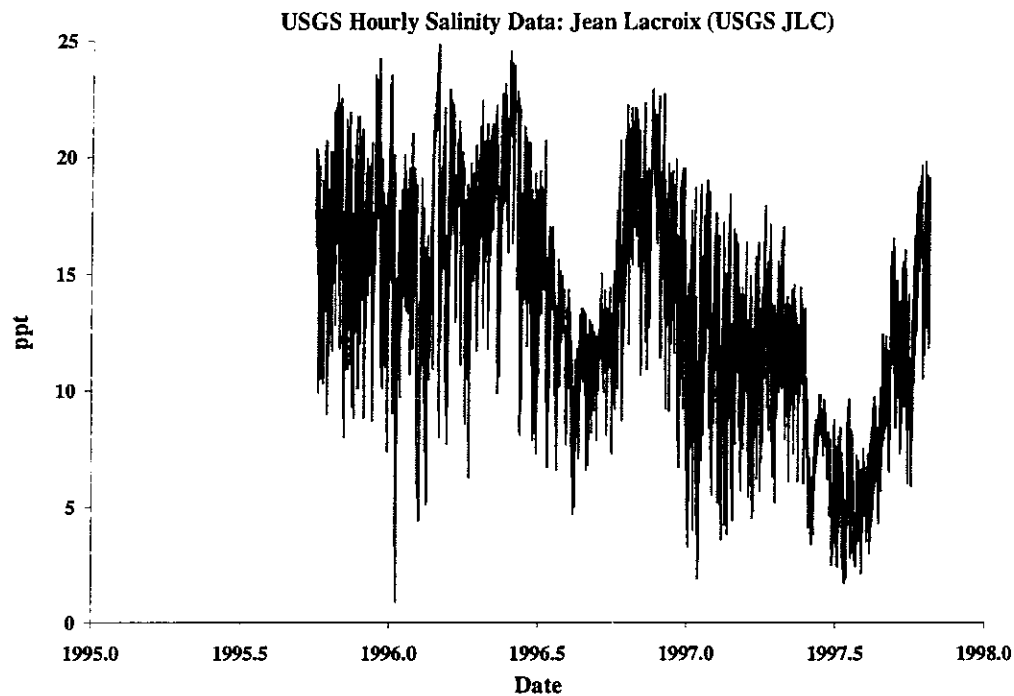


Figure 4.18. Plot of hourly salinity from the USGS station in Bayou Jean Lacroix (USGS JLC) over the time period from January, 1995 through December, 1997.

Boudreaux study area. This renewal time is most likely on the low side since it only includes surplus generated inside the project areas. It is likely that there are fresh water sources entering the project areas from the marshes outside of the project boundaries. In the case of the Lake Boudreaux study area, it appears that the project boundary encompasses about one half of the area over which surplus (which enters the project area) is being generated. Thus the estimates of freshwater input into the Lake Boudreaux project area are probably twice what is presented in Table 4.5. This could result in a much lower renewal time of (~65 days) for the Lake Boudreaux study area. In the case of the Grand Bayou Study area, the project area encompasses

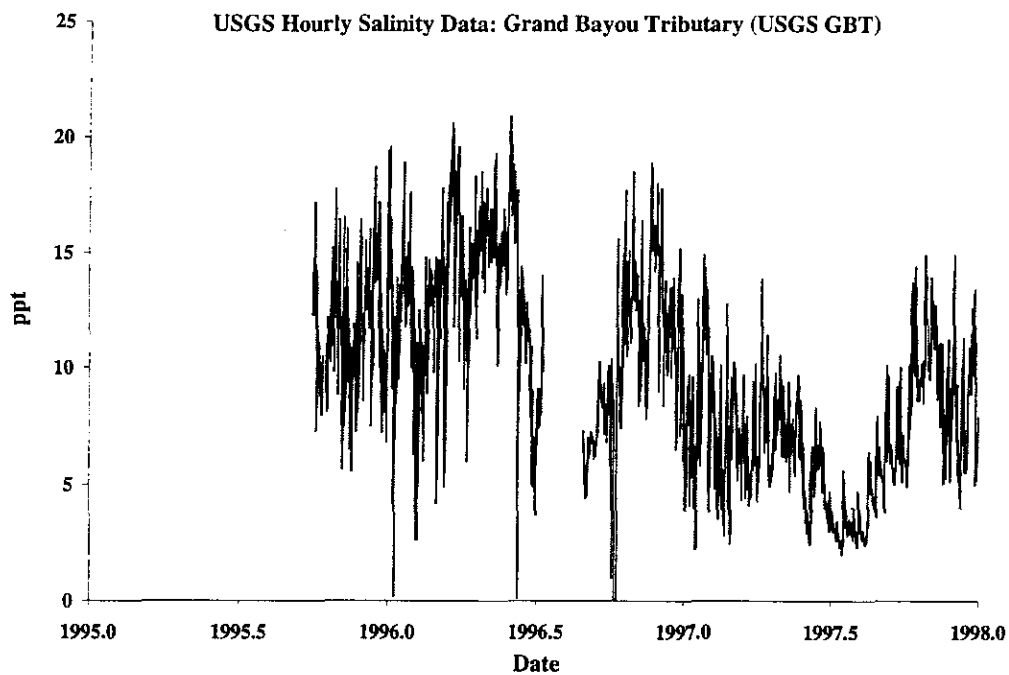


Figure 4.19. Plot of hourly salinity from the USGS station at in Grand Bayou Tributary (USGS GBT) over the time period from January, 1995 through December, 1997.

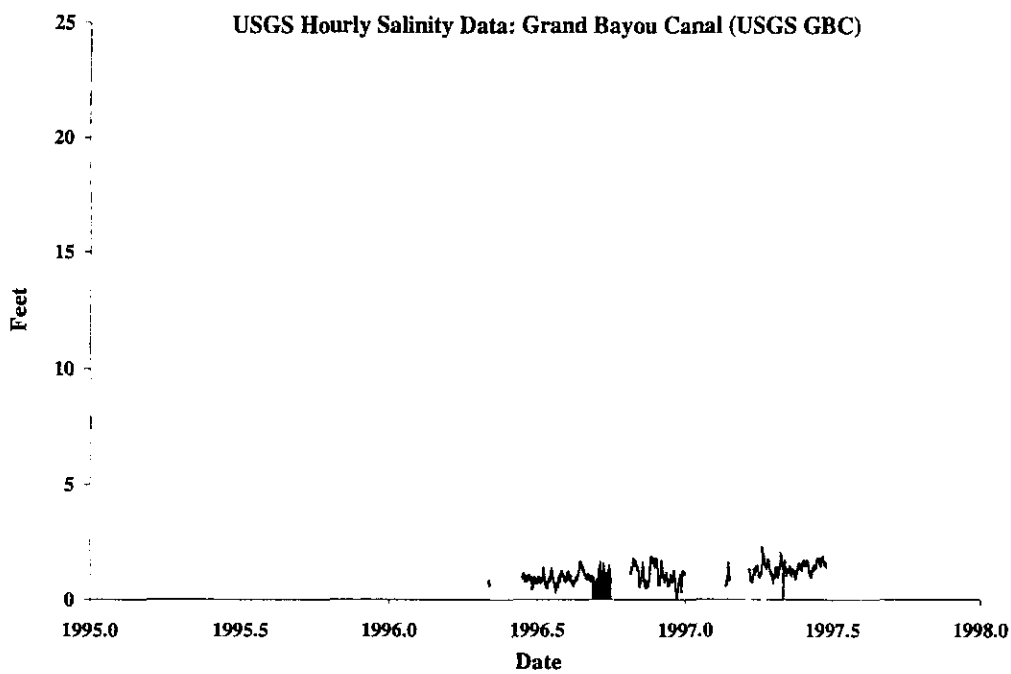


Figure 4.20 Plot of hourly salinity from the USGS station at in Grand Bayou Canal (USGS GBC) over the time period from January, 1995 through December, 1997.

Table 4.3. Water Budget summary for the Grand Bayou and Lake Boudreaux Study areas.

<b>Grand Bayou</b>								
Month	Water	Fresh	Int.	Rainfall generated surplus (cfs)				Total Input (ft3)
				Brack.	Shr/Scr	Other	Total	
Jan	104.0	45.4	44.7	113.9	2.9	5.5	316.5	8.5E+08
Feb	137.2	59.9	59.0	150.2	3.9	7.3	417.3	1.0E+09
Mar	70.0	30.5	30.1	76.6	2.0	3.7	212.9	5.7E+08
Apr	36.2	15.8	15.5	39.6	1.0	1.9	110.0	2.9E+08
May	-7.6	-3.3	-3.3	-8.3	-0.2	-0.4	-23.0	-6.2E+07
Jun	-8.8	-3.8	-3.8	-9.6	-0.2	-0.5	-26.8	-6.9E+07
Jul	-16.1	-7.0	-6.9	-17.6	-0.5	-0.9	-48.9	-1.3E+08
Aug	0.9	0.4	0.4	1.0	0.0	0.1	2.9	7.7E+06
Sep	11.7	5.1	5.0	12.8	0.3	0.6	35.7	9.2E+07
Oct	4.7	2.1	2.0	5.2	0.1	0.3	14.4	3.9E+07
Nov	63.5	27.7	27.3	69.5	1.8	3.4	193.3	5.0E+08
Dec	111.7	48.8	48.0	122.3	3.1	5.9	339.9	9.1E+08
Mean	42.3	18.5	18.2	46.3	1.2	2.2	128.7	3.3E+08
Total								4.0E+09

**Lake Boudreaux**

Month	Water	Fresh	Int.	Rainfall generated surplus (cfs)				Total Input (ft3)
				Brack.	Shr/Scr	Other	Total	
Jan	46.4	24.8	24.5	33.0	10.4	7.9	146.9	3.9E+08
Feb	61.2	32.7	32.2	43.5	13.7	10.4	193.7	4.7E+08
Mar	31.2	16.7	16.5	22.2	7.0	5.3	98.8	2.6E+08
Apr	16.1	8.6	8.5	11.5	3.6	2.7	51.1	1.3E+08
May	-3.4	-1.8	-1.8	-2.4	-0.8	-0.6	-10.7	-2.9E+07
Jun	-3.9	-2.1	-2.1	-2.8	-0.9	-0.7	-12.4	-3.2E+07
Jul	-7.2	-3.8	-3.8	-5.1	-1.6	-1.2	-22.7	-6.1E+07
Aug	0.4	0.2	0.2	0.3	0.1	0.1	1.3	3.6E+06
Sep	5.2	2.8	2.8	3.7	1.2	0.9	16.6	4.3E+07
Oct	2.1	1.1	1.1	1.5	0.5	0.4	6.7	1.8E+07
Nov	28.4	15.1	14.9	20.1	6.3	4.8	89.7	2.3E+08
Dec	49.9	26.6	26.3	35.4	11.1	8.5	157.8	4.2E+08
Mean	18.9	10.1	9.9	13.4	4.2	3.2	59.7	1.5E+08
Total								1.9E+09

Table 4.4. Estimation of total volume of water in the Grand Bayou Study area and the renewal time based on the mean rainfall generated surplus.

Category	Area (hectares)	Area (acres)	Area (sq m)	Percent water	Depth (cm)	Volume (m3)	Volume (ft3)
Fresh 1	35	8.52E+01	3.45E+05	5.0	10.0	1.72E+03	6.09E+04
Fresh 2	329	8.12E+02	3.28E+06	7.5	10.0	2.46E+04	8.70E+05
Fresh 3	704	1.74E+03	7.04E+06	17.5	10.0	1.23E+05	4.35E+06
Fresh 4	240	5.94E+02	2.40E+06	32.5	10.0	7.81E+04	2.76E+06
Fresh 5	505	1.25E+03	5.04E+06	50.0	10.0	2.52E+05	8.90E+06
Fresh 6	81	2.01E+02	8.13E+05	70.0	10.0	5.69E+04	2.01E+06
Oligo 1	16	4.03E+01	1.63E+05	5.0	15.0	1.22E+03	4.31E+04
Oligo 2	132	3.27E+02	1.32E+06	7.5	15.0	1.49E+04	5.25E+05
Oligo 3	1,456	3.60E+03	1.46E+07	17.5	15.0	3.82E+05	1.35E+07
Oligo 4	816	2.02E+03	8.15E+06	32.5	15.0	3.98E+05	1.40E+07
Oligo 5	662	1.64E+03	6.62E+06	50.0	15.0	4.96E+05	1.75E+07
Oligo 6	14	3.48E+01	1.41E+05	70.0	15.0	1.48E+04	5.23E+05
Meso 1	0	0.00E+00	0.00E+00	5.0	20.0	0.00E+00	0.00E+00
Meso 2	254	6.27E+02	2.54E+06	7.5	20.0	3.81E+04	1.34E+06
Meso 3	794	1.96E+03	7.94E+06	17.5	20.0	2.78E+05	9.81E+06
Meso 4	2,325	5.74E+03	2.32E+07	32.5	20.0	1.51E+06	5.34E+07
Meso 5	4,321	1.07E+04	4.32E+07	50.0	20.0	4.32E+06	1.53E+08
Meso 6	1,291	3.19E+03	1.29E+07	70.0	20.0	1.81E+06	6.38E+07
Poly 1	0	0.00E+00	0.00E+00	5.0	30.0	0.00E+00	0.00E+00
Poly 2	1	2.47E+00	1.00E+04	7.5	30.0	2.25E+02	7.94E+03
Poly 3	17	4.10E+01	1.66E+05	17.5	30.0	8.71E+03	3.08E+05
Poly 4	13	3.09E+01	1.25E+05	32.5	30.0	1.22E+04	4.30E+05
Poly 5	118	2.91E+02	1.18E+06	50.0	30.0	1.77E+05	6.25E+06
Poly 6	0	0.00E+00	0.00E+00	70.0	30.0	0.00E+00	0.00E+00
Open Water	4,897	1.21E+04	4.90E+07	100.0	50.0	2.45E+07	8.64E+08
Canals	2,296	5.67E+03	2.30E+07	100.0	100.0	2.30E+07	8.10E+08
<b>Total</b>	<b>21,317</b>	<b>5.27E+04</b>	<b>2.13E+08</b>			<b>5.74E+07</b>	<b>2.03E+09</b>
Average FW input:	128.7 cfs						
Total FW input:	4.0E+09 cubic feet						
FW Renewal time:	182 days						

Table 4.5. Estimation of total volume of water in the Lake Boudreaux Study area and the renewal time based on the mean rainfall generated surplus.

Category	Area (hectares)	Area (acres)	Area (sq m)	Percent water	Depth (m)	Volume (m3)	Volume (ft3)
Fresh 1	43	1.07E+02	4.34E+05	5.0	0.10	2.17E+03	7.66E+04
Fresh 2	84	2.08E+02	8.44E+05	7.5	0.10	6.33E+03	2.23E+05
Fresh 3	86	2.12E+02	8.60E+05	17.5	0.10	1.50E+04	5.31E+05
Fresh 4	177	4.36E+02	1.76E+06	32.5	0.10	5.73E+04	2.02E+06
Fresh 5	272	6.72E+02	2.72E+06	50.0	0.10	1.36E+05	4.80E+06
Fresh 6	7	1.83E+01	7.40E+04	70.0	0.10	5.18E+03	1.83E+05
Oligo 1	11	2.77E+01	1.12E+05	5.0	0.10	5.60E+02	1.98E+04
Oligo 2	139	3.43E+02	1.39E+06	7.5	0.10	1.04E+04	3.67E+05
Oligo 3	374	9.25E+02	3.74E+06	17.5	0.10	6.55E+04	2.31E+06
Oligo 4	448	1.11E+03	4.48E+06	32.5	0.10	1.45E+05	5.14E+06
Oligo 5	714	1.76E+03	7.14E+06	50.0	0.10	3.57E+05	1.26E+07
Oligo 6	142	3.51E+02	1.42E+06	70.0	0.10	9.94E+04	3.51E+06
Meso 1	7	1.68E+01	6.80E+04	5.0	0.15	5.10E+02	1.80E+04
Meso 2	120	2.96E+02	1.20E+06	7.5	0.15	1.35E+04	4.76E+05
Meso 3	382	9.43E+02	3.82E+06	17.5	0.15	1.00E+05	3.54E+06
Meso 4	667	1.65E+03	6.67E+06	32.5	0.15	3.25E+05	1.15E+07
Meso 5	983	2.43E+03	9.82E+06	50.0	0.15	7.37E+05	2.60E+07
Meso 6	262	6.47E+02	2.62E+06	70.0	0.15	2.75E+05	9.71E+06
Poly 1	0	0.00E+00	0.00E+00	5.0	0.30	0.00E+00	0.00E+00
Poly 2	0	0.00E+00	0.00E+00	7.5	0.30	0.00E+00	0.00E+00
Poly 3	0	0.00E+00	0.00E+00	17.5	0.30	0.00E+00	0.00E+00
Poly 4	28	6.97E+01	2.82E+05	32.5	0.30	2.75E+04	9.70E+05
Poly 5	86	2.12E+02	8.58E+05	50.0	0.30	1.29E+05	4.54E+06
Poly 6	2	4.20E+00	1.70E+04	70.0	0.30	3.57E+03	1.26E+05
Open Water	2,430	6.00E+03	2.43E+07	100.0	0.50	1.21E+07	4.29E+08
Canals	828	2.05E+03	8.28E+06	100.0	1.00	8.28E+06	2.92E+08
<b>Total</b>	<b>8,293</b>	<b>2.05E+04</b>	<b>8.29E+07</b>			<b>2.29E+07</b>	<b>8.10E+08</b>
FW input:	59.7 cfs						
Total FW Input:	1.9E+09 cubic feet						
FW Renewal time:	157 days						

most of the marshes over which the surplus is being generated. The exception would be water entering the system from the Intracoastal waterway through an existing connection. The USGS continuously measured water velocities in this connection from May through October 1996. The mean velocity in the channel was 0.32 ft s<sup>-1</sup> (10 cm s<sup>-1</sup>) with a maximum of 1.21 ft s<sup>-1</sup> (37.0 cm s<sup>-1</sup>). Although we did not measure the cross-section for the channel it is around 450 to 500 ft<sup>2</sup> (18.6 m<sup>2</sup>). (Ronny Paille, USFWS personal communication). The USGS measured flows up to ~520 cfs under high flow conditions in this channel )Ronny Paille, USFWS personal communication). Since the velocity data indicate the average flow is about 27 percent of the maximum flow, this channel could be supplying about 150 cfs (1.8 m s<sup>-1</sup>) under average flow conditions. This could add about on third more water that what was calculated in Table 4.4 to the Grand Bayou study area. This would result in a lower renewal time (~60 days) for the Grand Bayou study area.

The estimations of the tidal prism volume and the renewal time using the tidal prism volume are presented in Tables 4.6 and 4.7 for the Grand Bayou Study area and the Lake Boudreaux Study area respectively. The estimated tidal prism volume for the Grand Bayou Study area is 2.8 x 10<sup>8</sup> ft<sup>3</sup> (7.9x 10<sup>6</sup> m<sup>3</sup>), and the estimated tidal prism volume for the Lake Boudreaux Study area is 9.8x 10<sup>7</sup> ft<sup>3</sup> (2.8 x10<sup>6</sup> m<sup>3</sup>). For comparison, the tidal prism for the entire Terrebonne Basin was estimated by Wisemann and Swenson (1989) to be 1.8 x10<sup>10</sup> ft<sup>3</sup> (5.2 x10<sup>8</sup> m<sup>3</sup>). These tidal prisms correspond to a tidal flux of 3,113 cfs for the Grand Bayou Study area and 1,093 cfs for the Lake Boudreaux Study area. Using these figures, the replacement time would be 7.5 days for the water in the Grand Bayou Study area, and 8.6 days for the water in the Lake Boudreaux Study area. This calculation assumes complete replacement of water on each tidal cycle. This is usually not the case, since the water is advected back and forth on each tidal cycle and is progressively mixed over numerous tidal cycles. However, the numbers due point out the potential importance of the tidal forcing in the system. Byrne et al. (1976) estimated that it required ~80 tidal cycles (83 days) for a 99% renewal. volume change in what the authors referred to as "The Barataria Management Unit". Wiseman and Swenson (1989), calculated that the time required to flush a concentration down to ~10% of its initial value was ~52 tidal cycles (1.75 months) for the Barataria System.

Table 4.6. Estimation of the volume of the tidal prism in the Grand Bayou Study area and the renewal time based on the estimated tidal flux.

Category	Area (hectares)	Area (acres)	Area (sq m)	Tide (cm)	Volume (m3)	Volume (ft3)	Flux (cfs)	Yearly Total (ft3)
Fresh 1	35	8.52E+01	3.45E+05	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 2	329	8.12E+02	3.28E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 3	704	1.74E+03	7.04E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 4	240	5.94E+02	2.40E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 5	505	1.25E+03	5.04E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 6	81	2.01E+02	8.13E+05	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh OW	657	1.62E+03	6.56E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh Canals	308	7.60E+02	3.08E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Oligo 1	16	4.03E+01	1.63E+05	2.0	3.26E+03	1.15E+05	1.3	4.0E+07
Oligo 2	132	3.27E+02	1.32E+06	2.0	2.64E+04	9.34E+05	10.4	3.3E+08
Oligo 3	1,456	3.60E+03	1.46E+07	2.0	2.91E+05	1.03E+07	114.2	3.6E+09
Oligo 4	816	2.02E+03	8.15E+06	2.0	1.63E+05	5.76E+06	64.0	2.0E+09
Oligo 5	662	1.64E+03	6.62E+06	2.0	1.32E+05	4.67E+06	51.9	1.6E+09
Oligo 6	14	3.48E+01	1.41E+05	2.0	2.82E+03	9.95E+04	1.1	3.5E+07
Oligo OW	1,074	2.65E+03	1.07E+07	2.0	2.15E+05	7.58E+06	84.2	2.7E+09
Oligo Canals	503	1.24E+03	5.03E+06	2.0	1.01E+05	3.55E+06	39.5	1.2E+09
Meso 1	0	0.00E+00	0.00E+00	5.0	0.00E+00	0.00E+00	0.0	0.0E+00
Meso 2	254	6.27E+02	2.54E+06	5.0	1.27E+05	4.48E+06	49.8	1.6E+09
Meso 3	794	1.96E+03	7.94E+06	5.0	3.97E+05	1.40E+07	155.7	4.9E+09
Meso 4	2,325	5.74E+03	2.32E+07	5.0	1.16E+06	4.10E+07	456.0	1.4E+10
Meso 5	4,321	1.07E+04	4.32E+07	5.0	2.16E+06	7.63E+07	847.3	2.7E+10
Meso 6	1,291	3.19E+03	1.29E+07	5.0	6.45E+05	2.28E+07	253.2	8.0E+09
Meso OW	3,116	7.70E+03	3.11E+07	5.0	1.56E+06	5.50E+07	610.9	1.9E+10
Meso Canals	1,461	3.61E+03	1.46E+07	5.0	7.30E+05	2.58E+07	286.4	9.0E+09
Poly 1	0	0.00E+00	0.00E+00	10.0	0.00E+00	0.00E+00	0.0	0.0E+00
Poly 2	1	2.47E+00	1.00E+04	10.0	1.00E+03	3.53E+04	0.4	1.2E+07
Poly 3	17	4.10E+01	1.66E+05	10.0	1.66E+04	5.86E+05	6.5	2.1E+08
Poly 4	13	3.09E+01	1.25E+05	10.0	1.25E+04	4.41E+05	4.9	1.5E+08
Poly 5	118	2.91E+02	1.18E+06	10.0	1.18E+05	4.16E+06	46.3	1.5E+09
Poly 6	0	0.00E+00	0.00E+00	10.0	0.00E+00	0.00E+00	0.0	0.0E+00
Poly OW	51	1.27E+02	5.13E+05	10.0	5.13E+04	1.81E+06	20.1	6.4E+08
Poly Canals	24	5.95E+01	2.41E+05	10.0	2.41E+04	8.50E+05	9.4	3.0E+08
Total	21,316	5.27E+04	2.13E+08		7.94E+06	2.80E+08	3113.5	9.8E+10
System Volume	2.E+09	cubic feet						
Renewal time	48.4	renewals per year						
Renewal time	7.5	days per renewal						

Table 4.7. Estimation of the volume of the tidal prism in the Lake Boudreaux Study area and the renewal time based on the estimated tidal flux.

Category	Area (hectares)	Area (acres)	Area (sq m)	Tide (cm)	Volume (m3)	Volume (ft3)	Flux (cfs)	Yearly Total (ft3)
Fresh 1	43	107	4.34E+05	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 2	84	208	8.44E+05	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 3	86	212	8.60E+05	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 4	177	436	1.76E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 5	272	672	2.72E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh 6	7	18	7.40E+04	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh OW	323	798	3.23E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Fresh Canals	110	272	1.10E+06	0.0	0.00E+00	0.00E+00	0.0	0.0E+00
Oligo 1	11	28	1.12E+05	2.0	2.24E+03	7.91E+04	0.9	2.8E+07
Oligo 2	139	343	1.39E+06	2.0	2.77E+04	9.79E+05	10.9	3.4E+08
Oligo 3	374	925	3.74E+06	2.0	7.49E+04	2.64E+06	29.4	9.3E+08
Oligo 4	448	1,106	4.48E+06	2.0	8.95E+04	3.16E+06	35.1	1.1E+09
Oligo 5	714	1,764	7.14E+06	2.0	1.43E+05	5.04E+06	56.0	1.8E+09
Oligo 6	142	351	1.42E+06	2.0	2.84E+04	1.00E+06	11.1	3.5E+08
Oligo OW	883	2,180	8.82E+06	2.0	1.76E+05	6.23E+06	69.2	2.2E+09
Oligo Canals	301	743	3.01E+06	2.0	6.01E+04	2.12E+06	23.6	7.4E+08
Meso 1	7	17	6.80E+04	5.0	3.40E+03	1.20E+05	1.3	4.2E+07
Meso 2	120	296	1.20E+06	5.0	5.99E+04	2.12E+06	23.5	7.4E+08
Meso 3	382	943	3.82E+06	5.0	1.91E+05	6.74E+06	74.9	2.4E+09
Meso 4	667	1,648	6.67E+06	5.0	3.33E+05	1.18E+07	130.8	4.1E+09
Meso 5	983	2,428	9.82E+06	5.0	4.91E+05	1.73E+07	192.7	6.1E+09
Meso 6	262	647	2.62E+06	5.0	1.31E+05	4.62E+06	51.4	1.6E+09
Meso OW	1,168	2,886	1.17E+07	5.0	5.84E+05	2.06E+07	229.1	7.2E+09
Meso Canals	398	983	3.98E+06	5.0	1.99E+05	7.03E+06	78.1	2.5E+09
Poly 1	0	0	0.00E+00	10.0	0.00E+00	0.00E+00	0.0	0.0E+00
Poly 2	0	0	0.00E+00	10.0	0.00E+00	0.00E+00	0.0	0.0E+00
Poly 3	28	70	2.82E+05	10.0	2.82E+04	9.95E+05	11.1	3.5E+08
Poly 4	86	212	8.58E+05	10.0	8.58E+04	3.03E+06	33.6	1.1E+09
Poly 5	2	4	1.70E+04	10.0	1.70E+03	6.00E+04	0.7	2.1E+07
Poly 6	0	0	0.00E+00	10.0	0.00E+00	0.00E+00	0.0	0.0E+00
Poly OW	56	138	5.58E+05	10.0	5.58E+04	1.97E+06	21.9	6.9E+08
Poly Canals	19	47	1.90E+05	10.0	1.90E+04	6.72E+05	7.5	2.4E+08
Total	8,292	20,481	8.29E+07		2.79E+06	9.83E+07	1092.7	3.4E+10
System Volume	8.E+08	cubic feet						
Renewal time	42.5	renewals per year						
Renewal time	8.6	days per renewal						

## Summary

The analysis of water level and salinity data from the Lake Boudreaux and Grand Bayou Study areas yielded the following results:

- Relative sea level rise in the area ranges from 0.77 to 1.49 cm yr<sup>-1</sup>.
- The total water level fluctuations (tides and wind events) observed are about 3.3 feet (100.6 cm), with the tidal forcing being about 1.0 feet (30.5 cm).
- Both study areas show a decrease in tidal amplitudes from 1 foot (30.5 cm) at the open water coastal endpoint to 0.1 foot (3 cm) at the northern end of the study areas.
- The canal network in the west side of the Grand Bayou Study area has a much higher tidal amplitude than would be expected, based on distance inland. This is most likely due to the canal providing a pathway into the study area.
- Salinity data from the area indicate that salinities in the southern portion of the study areas are typically around 10-12 ppt, although values of 20-30 ppt have been observed.
- Salinity data from Bayou Lafourche (at Leeville) and Petite Caillou (at Cocodrie) show greatly reduced salinities due the freshwater input from these bayous.
- Discrete salinity data indicate that the Lake Boudreaux study area can have a fairly strong (~5 ppt) north to south salinity gradient and a weaker (~1 ppt) east to west salinity gradient. The east west gradient may be due to a canal network which allows saltier water to penetrate into the study area along the east side.
- Water budget calculations yielded a mean surplus (generated in the project area) of 128.7 cfs for the Grand Bayou study area and 59.7 cfs for the Lake Boudreaux study area. If these surpluses are adjusted for areas (and freshwater sources) not accounted for in the project area the values are ~119 cfs for the Lake Bodreaux study area and 171 cfs for the Grand Bayou study area.
- The calculated freshwater renewal times are 65 to 157 days for the Lake Boudreaux study area and 60 to 182 days for the Grand Bayou study area. The range in values results from then uncertainty in the surplus estimate from areas outside the project area.
- The calculated renewal time for tidal prism exchange is 8.6 days for the Lake Boudreaux study area and 7.5 days for the Grand Bayou study area. These numbers represent the renewal times that would occur with complete mixing on each tidal cycle.

## CHAPTER 5: SOIL BULK PROPERTIES

### Introduction

Soil bulk properties—bulk density, live root mat thickness, and soil strength—when evaluated together, are indicators of substrate integrity. Typically, saline marshes exhibit high bulk density ( $>0.2 \text{ g cm}^{-3}$ ), with the converse true for freshwater peats ( $<0.1 \text{ g cm}^{-3}$ ). These differences in bulk density are controlled largely by mineral sediment contents in the soil profile. In the case of highly organic soils (bulk density  $<0.1 \text{ g cm}^{-3}$ ), peat production is the dominant form of marsh accretion (McCaffrey and Thomson 1980, Hatton et al. 1983, Bricker-Urso et al. 1989, Craft et al. 1993, Nyman et al. 1995), resulting from the burial of shoot, root, and rhizome material under anoxic substrate conditions. The bulk variables we measured were designed to yield a synoptic view of the upper substrate (the upper 40 cm) integrity without employing the time-consuming method of belowground biomass separation (live vs. dead; fibric vs. sapric peat).

Belowground root production and peat decomposition are opposing forces that govern the strength of an organic soil matrix over seasonal and long-term intervals. To measure the strength of these soils, we used a Torvane strength tester (see methods) that measures the force required to produce shear failure of a soil sample. This strength measurement correlates ( $r=0.72$ ) well with the live, macro-organic matter content (roots and rhizomes retained by a 1.0 mm sieve) (van Eerd 1985, McGinnis 1997); therefore, the strength measurement is a proxy for live belowground standing stock, and it is useful for comparisons among sites.

Bulk density is almost entirely controlled by the concentration of mineral matter with negligible influence from organic matter (Gosselink et al. 1984). Organic soils that have bulk densities greater than  $0.2 \text{ g cm}^{-3}$  usually contain greater than 60% mineral material by volume; on the contrary, bulk densities below  $0.1 \text{ g cm}^{-3}$  usually contain greater than 60% organic material by volume (Holm et al. 2000). Although mineral sediments have been implicated with increased plant productivity (Bricker-Urso, 1989), no correlation between soil strength and mineral content in wetland soils has been observed (McGinnis 1997).

The thickness or depth of the rooted layer is a semi-quantitative estimate of the live root content and the cohesive potential of the upper soil layer. Live root-mats of freshwater, *Panicum*

*hemitomon*-dominated substrates may extend up to 45 cm in thickness (Sasser 1994); whereas oligohaline to brackish marshes dominated by *Spartina patens* may have live root depths less than 24 cm (McGinnis 1997).

## Methods

We collected soil samples from 31 sites among the two distinct study areas designated as Grand Bayou and Lake Boudreaux, in Terrebonne Basin. We used a 7.6 cm core tube (thin wall aluminum) to collect a single soil sample that ranged in depth from 30 to 50 cm. This core was transported to the laboratory for bulk property and soil strength analyses. Another core was collected and extruded on site to determine the live rooting depth by a combination of visual inspection and the "natural" breaking point, i.e. where the live root mat detaches from the underlying decomposed fraction.

Percentage soil organic matter, mineral concentration, bulk density, and soil strength were measured on 5 cm depth intervals. The core was cut into 5 cm sections from the surface down to the bottom layers (40-50 cm). For bulk density, we dried the 5 cm sections to a constant weight (0.01g). This weight was divided by a core volume ( $226.8 \text{ cm}^3$ ) to yield dry bulk density. After grinding the entire dry soil sample, approximately 1.0 g of the material was burned in a muffle furnace at 550 °C for 2 hours and re-weighed to determine the remaining amount of ash, which represents the mineral concentration of the soil sample. Soil strength (Trodden Soiltest Torvane, ELE International, Lake Bluff, Illinois) was measured ( $\text{kg cm}^{-2}$ ), at field moisture, on the upper and lower faces of each 5 cm soil sample; these two values were averaged to represent the soil strength of that depth interval. We used the 1.0 vane, which yields values that require no correction. Our analyses of bulk properties comprised the upper 40 cm of soil for both basins.

## Results and Discussion

No significant differences were found for soil bulk properties that were averaged among the two basins; in fact, bulk density, root mat thickness, and soil strength were practically identical (Table 5.1). Bulk density, in the lower portions of each study area, exceeded that of the upper portions of the study areas (Table 5.2). With depth in the soil profile, the soil strength

Table 5.1. Average values of soil strength, bulk density, root mat thickness, and soil salinity by study area. Soil bulk density and strength were measured on each 5-cm interval to a total depth of 40 cm; two measurements of soil strength were taken on each 5-cm section. Root mat thickness was measured in the field for each site. Soil salinity, in the upper reaches of each basin, was measured 15-20 cm below the marsh surface in the field (29, 30 May 2001). The number of samples is indicated for Grand Bayou and Lake Boudreaux study areas, respectively.

parameter	n	Grand Bayou	Lake Boudreaux
soil strength ( $\text{kg cm}^{-2}$ )	131, 103	$0.180 \pm 0.012$	$0.188 \pm 0.010$
root mat thickness (cm)	17, 14	$19 \pm 10.5$	$18.8 \pm 11.1$
dry bulk density ( $\text{g cm}^{-3}$ )	131, 103	$0.109 \pm 0.007$	$0.092 \pm 0.005$
soil salinity	5, 4	$4.0 \pm 2.0$	$8.8 \pm 3.6$

Table 5.2. Average values of soil strength and bulk density by location (upper/lower basin) within Grand Bayou and Lake Boudreaux study areas.

parameter	Grand Bayou		Lake Boudreaux	
	upper basin	lower basin	upper basin	lower basin
soil strength ( $\text{kg cm}^{-2}$ )	$0.19 \pm 0.2$	$0.17 \pm 0.02$	$0.18 \pm 0.01$	$0.19 \pm 0.02$
dry bulk density ( $\text{g cm}^{-3}$ )	$0.08 \pm 0.004$	$0.13 \pm 0.012$	$0.07 \pm 0.005$	$0.12 \pm 0.008$

varied little among the basins, with the exception of Grand Bayou exhibiting greater soil strength in the upper 5 cm compared to Lake Boudreaux (Figure 5.1). In this study, soil strength in the upper 15 cm (the live root zone) of both study areas was significantly less than that of McGinnis (1997), who measured the strength of soils associated with vegetated, *Spartina patens* hummocks (Figure 5.1).

With respect to bulk density, the substrate among the study areas is within the range of values reported by Sasser et al. (1994) for freshwater and oligohaline marshes in Barataria Terrebonne basins. However, bulk densities ( $0.09\text{-}0.11 \text{ g cm}^{-3}$ ) exhibited by the soils in these

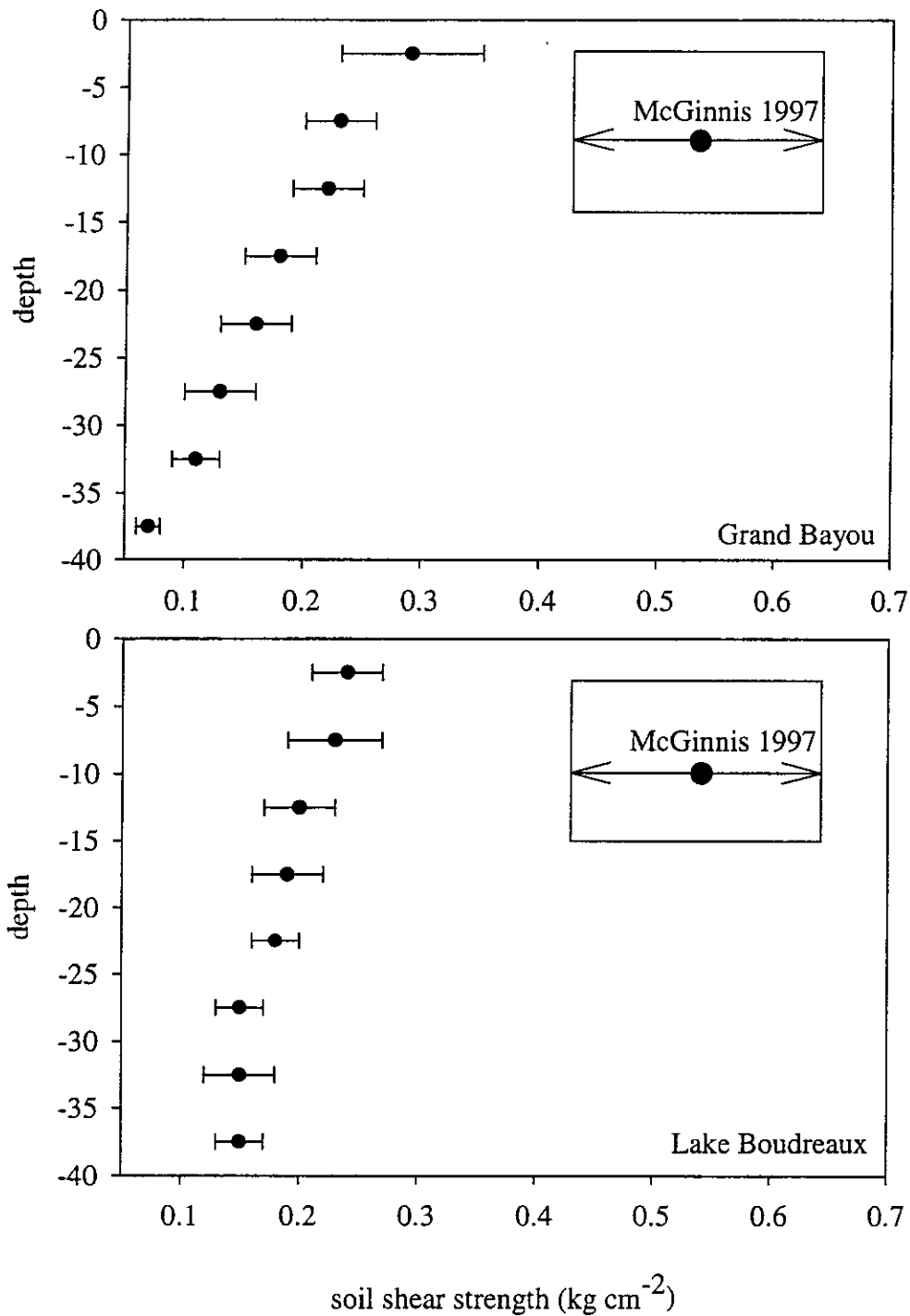


Figure 5.1. Depth profile of soil shear strength for Grand Bayou (upper; total of 17 cores) and Lake Boudreaux (lower; total of 14 cores) study areas. Soil shear strength of vegetated hummocks of *Spartina patens* exhibited a range of 0.42 to 0.66 kg cm<sup>-2</sup> within the upper 14 cm of the soil profile (McGinnis 1997); thus, soil strength from the present study is considerably less than McGinnis' (1997) values.

study areas are considered too low to support the development of saline marsh dominated by *Spartina alterniflora*. Other researchers (Nyman et al. 1995, DeLaune et al. 1990, Pezeshki and DeLaune 1988) have proposed that formation of healthy *Spartina alterniflora* marshes require bulk densities of  $0.25 \text{ g cm}^{-3}$  or greater. This prediction is based on the premise that mineral sediments—which usually have high iron concentrations—precipitate sulfides that otherwise would reach toxic levels in the root zone. Thus, if saltwater and flooding stress were to increase in peat-dominated substrates without concomitant increases in mineral sedimentation, it is expected that *Spartina patens* communities could retrograde into open-water communities rather than simply being replaced by the more salt-tolerant grass, *Spartina alterniflora*. Nonetheless, increasing soil bulk density is associated with more saline marsh types within both of these study areas (Figure 5.2)

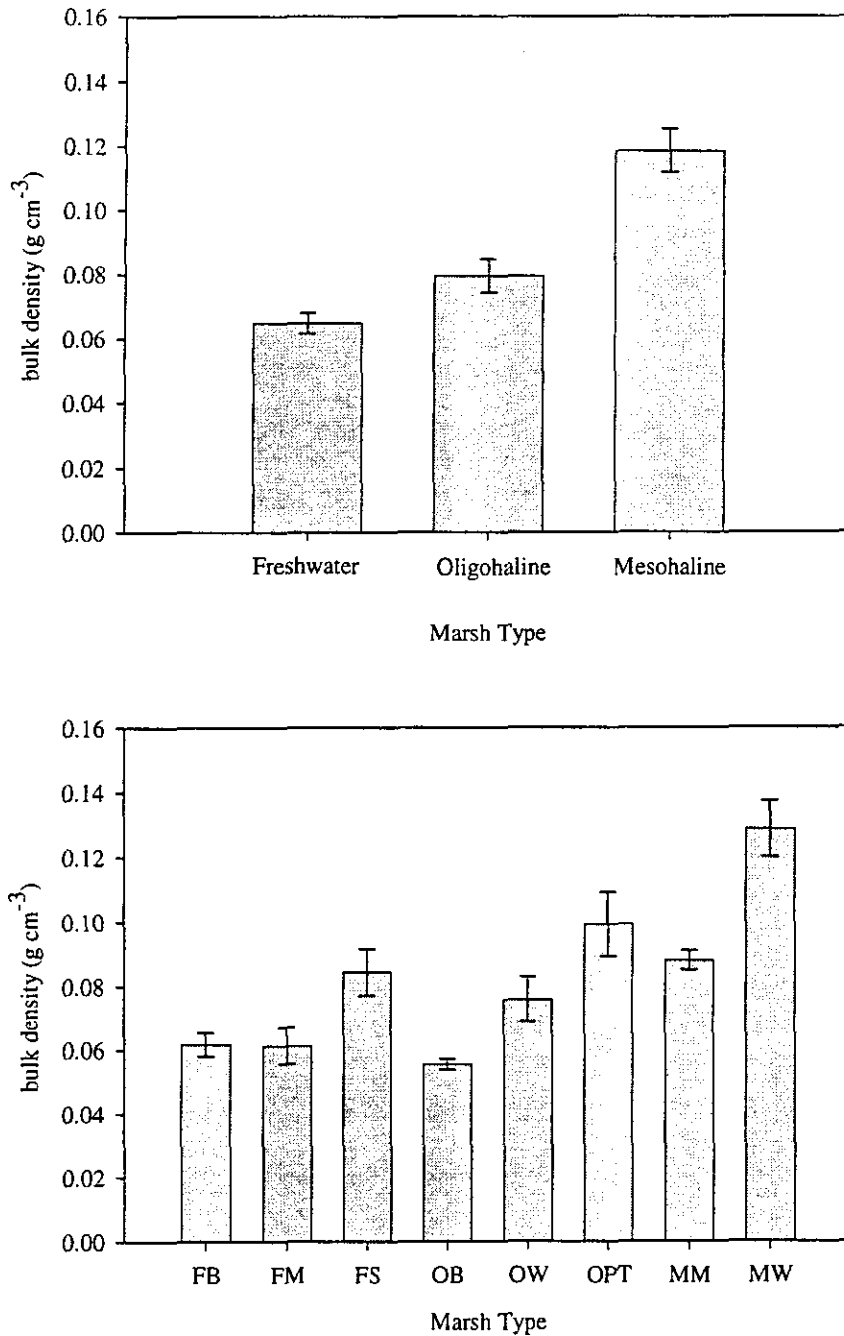


Figure 5.2. Bulk density of marsh soils (0-30 cm) by vegetation type. The upper graph displays a positive trend between soil bulk density as a function of increasing salinity. The upper graph comprises the means from each type from the lower graph. The types are as follows: fresh bulltongue (FB), maidencane (FM), spikerush (FS), oligohaline bulltongue (OB), wiregrass (OW), paspalum transition (OPT), mesohaline mix (MM), mesohaline wiregrass (MW).

## CHAPTER 6: SEDIMENT ACCRETION

### Introduction

Vertical marsh accretion is largely controlled by the accumulation of organic matter in emergent marshes (McCaffrey and Thomson 1980, Nyman et al. 1993, Turner, Swenson, and Milan 2001). However, mineral sediments provide additional nutrients that stimulate plant production (Bricker-Urso et al. 1989) and precipitate phytotoxins such as sulfide (Pezeshki and DeLaune 1988, Nyman 1990). Accretion rates can be measured using patterns of  $^{137}\text{Cs}$  in wetland soils (DeLaune et al 1978, DeLaune et al 1983, Milan et al 1994). This radioisotope is a residual of bomb fallout, which first appeared in 1954, peaked in the spring, 1963, with additional large amounts in 1964, and has declined since with minor fluctuations. The radioisotopic activity of  $^{137}\text{Cs}$  deposited with sediments can be used to date subsequent accretion above the 1954 or 1963 horizon, which corresponds with an "initial" or "maximum" isotopic deposition, respectively. The depth of the peak or "maximum"  $^{137}\text{Cs}$  activity (1963) was used for our analyses.

### Methods

Sediment accretion was measured by counting (with a gamma counter) the  $^{137}\text{Cs}$  activity as a function of distance down into a marsh core. This is a three step process: (1) the cores are sub-sampled into 1 cm sections; (2) the sections are dried; and (3) the activity in each section is counted using a Gamma counter. The basic procedure is outlined in Figure 6.1.

A 12 cm diameter core was collected using a stainless steel core tube. When collecting a core, the core tube was carefully inserted into the sediment between plants, and pushed down (using a twisting motion in order to limit compaction of the core) until the top of the core tube was within the upper 3 cm of the marsh. The depth of the core surface inside the tube and outside the tube was measured to ensure a minimum (<1.0 cm) amount of compaction; any cores exceeding 1.0 cm of compaction were discarded. Frozen sediment cores were extruded from the core tube and sectioned into 1.0 cm intervals using a band saw; losses from blade thickness (~0.3 cm) were compensated for in final calculations. The thickness of each section was measured with a digital micrometer at three locations around the perimeter to calculate its volume.

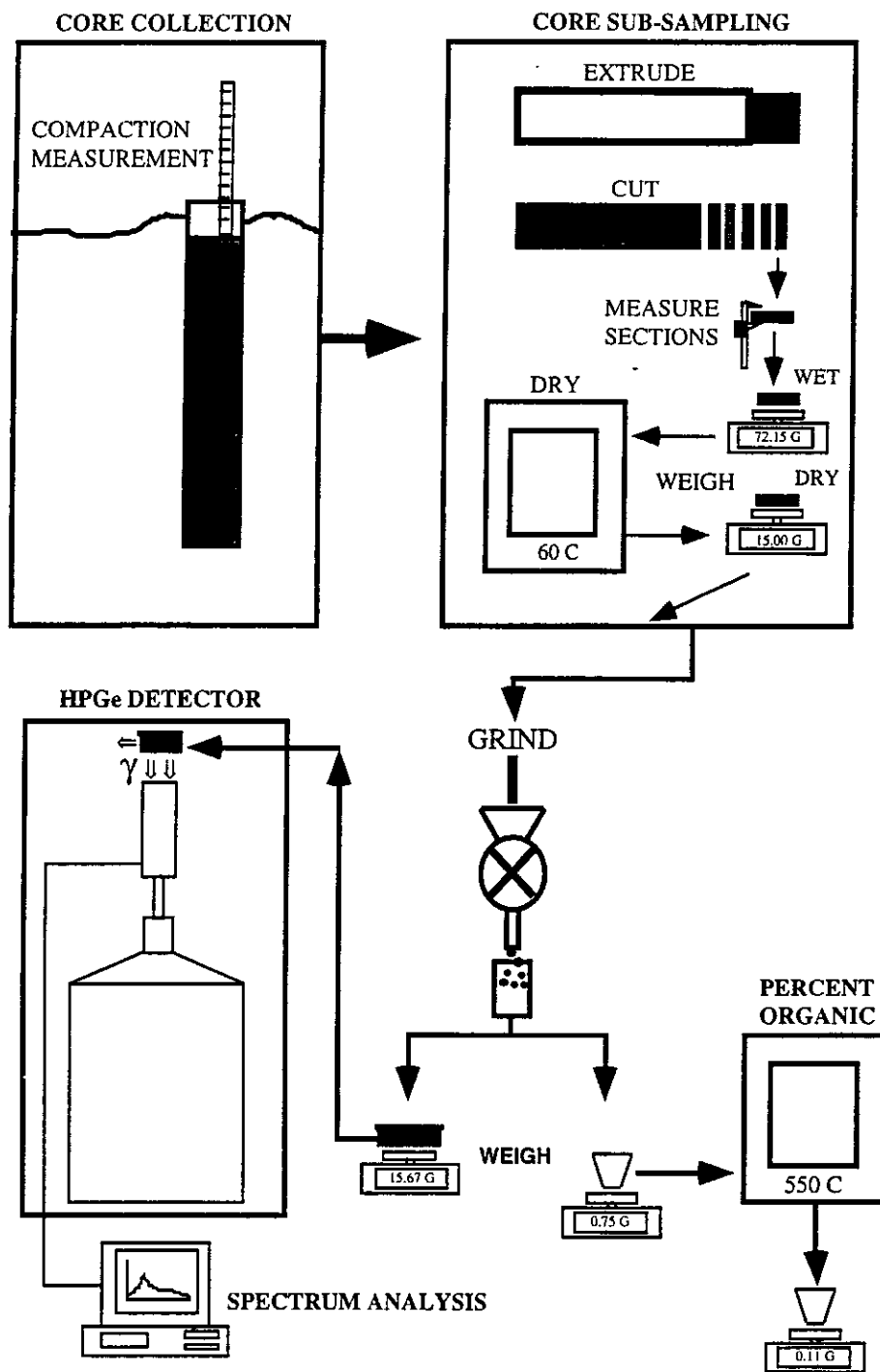


Figure 6.1. Outline of core processing for bulk density determination (dry weight of a known volume), percent organic determination (loss of material upon ignition at 550 degrees centigrade), and accretion determination (by analyzing for the peak in  $^{137}\text{Cs}$ ).

Sections were weighed (0.01 g), dried (60 °C), homogenized (with a Wiley grinding mill), and sub-sampled for gamma spectroscopy analysis.

Data were expressed as the relative activity (counts/second) per unit weight as a function of distance down the core. These values were used to determine the depth at which the peak (1963) in Cs activity occurs. The accretion rate was calculated by the following equation: accretion rate ( $\text{cm yr}^{-1}$ ) = depth to peak (cm) / (2000 - 1963). Mineral and organic concentrations were calculated for each 1 cm section so that their relative contributions to accretion could be compared with that of other studies.

## Results and Discussion

It should be noted that estimates of accretion rates from this study are conservative. We did not core directly through tussocks of vegetation; rather we cored the sediment between these tussocks. Average tussock elevation was not greater than 7 cm; however, if 7 cm was added to each of the cores, this adjustment would result in no more than  $0.2 \text{ cm yr}^{-1}$  of an increase in accretion rate. Data presented in the following figures and tables do not contain adjustments for tussock height. Previous studies do not always address disparities in coring technique (with respect to microsite topography), given that other studies (summarized by Turner et al. 2001) are usually conducted in saline marshes, which have greater homogeneity in microsite elevation than that of the habitat/growth form associated with *Spartina patens*.

Although four cores were analyzed for  $^{137}\text{Cs}$ , only three were useful for conducting accretion analysis; one core did not exhibit a discernable peak in cesium activity (Figures 6.2 and 6.3). So, our analysis comprised two cores from Grand Bayou study area and one core from the Lake Boudreaux study area. The core from the Lake Boudreaux site had the highest accretion rate ( $0.80 \text{ cm yr}^{-1}$ ) compared to the two sites in the Grand Bayou study area, which had accretion rates of  $0.66$  and  $0.71 \text{ cm yr}^{-1}$  (Table 6.1). The Lake Boudreaux site core was located streamside to Bayou Chauvin just north of Lake Baoudreaux, which may explain its relatively high rate of accretion compared to Grand Bayou sites. Mineral accumulation at the Lake Boudreaux site is 3 times higher than Grand Bayou sites (Table 6.1); thus, it is likely that mineral sediments that are resuspended from the lake bottom with storm tides are transported readily to the streamside marsh adjacent to Bayou Chauvin just north of Lake Boudreaux (Figure 6.4).

Table 6.1. Vertical accretion rates and associated contributions of organic and mineral material. Data from this study are compared with that of Nyman et al. 1993 (Terrebonne basin brackish marshes).

	accretion rate (cm yr <sup>-1</sup> )	organic accumulation (g m <sup>-2</sup> yr <sup>-1</sup> )	mineral accumulation (g m <sup>-2</sup> yr <sup>-1</sup> )	source
Lake Boudreaux	0.80	419	989	this study
Grand Bayou	0.66, 0.71	289-339	259-320	this study
Terrebonne brackish marshes	0.67-1.33	345-796	394-1054	Nyman et al. 1993*

\* Nyman et al. 1993 values based on a range of 5 cores

In general, the accretion rates from this study are within the lower range of other brackish marshes in Terrebonne basin (Figure 6.5, bottom graph) (Nyman et al. 1993). Grand Bayou sites had both organic and mineral accumulation rates that were lower than reported values (see Table 6.1). Organic matter accumulation exerts a strong influence on emergent marsh accretion (McCaffrey and Thomson 1980, Nyman et al. 1993, Turner et al. 2001). Apparently, saline marsh substrates exhibit an accumulation threshold of 200 g m<sup>-2</sup> yr<sup>-1</sup> of organic matter without further inorganic accumulation (Turner et al. 2001); however, this threshold is not necessarily applicable for less saline marshes. Although organic accumulation rates (289 and 339 g m<sup>-2</sup> yr<sup>-1</sup>) in the Grand Bayou region are above this threshold, they certainly are close to the minimum. By examining the bulk density and % organic matter profiles (Figures 6.2 and 6.3), it is evident that organic matter accumulation is by far the dominant form of accretion in the Grand Bayou study area; whereas, the Lake Boudreaux study area has appreciably more mineral sediment within the soil profile (Figure 6.3). Mineral sediments may enhance the productivity of emergent marshes indirectly by providing a nutrient subsidy (Bricker-Urso et al. 1989) and buffering the root zone from toxic levels of sulfides (Pezeshki and DeLaune 1988, Nyman 1990).

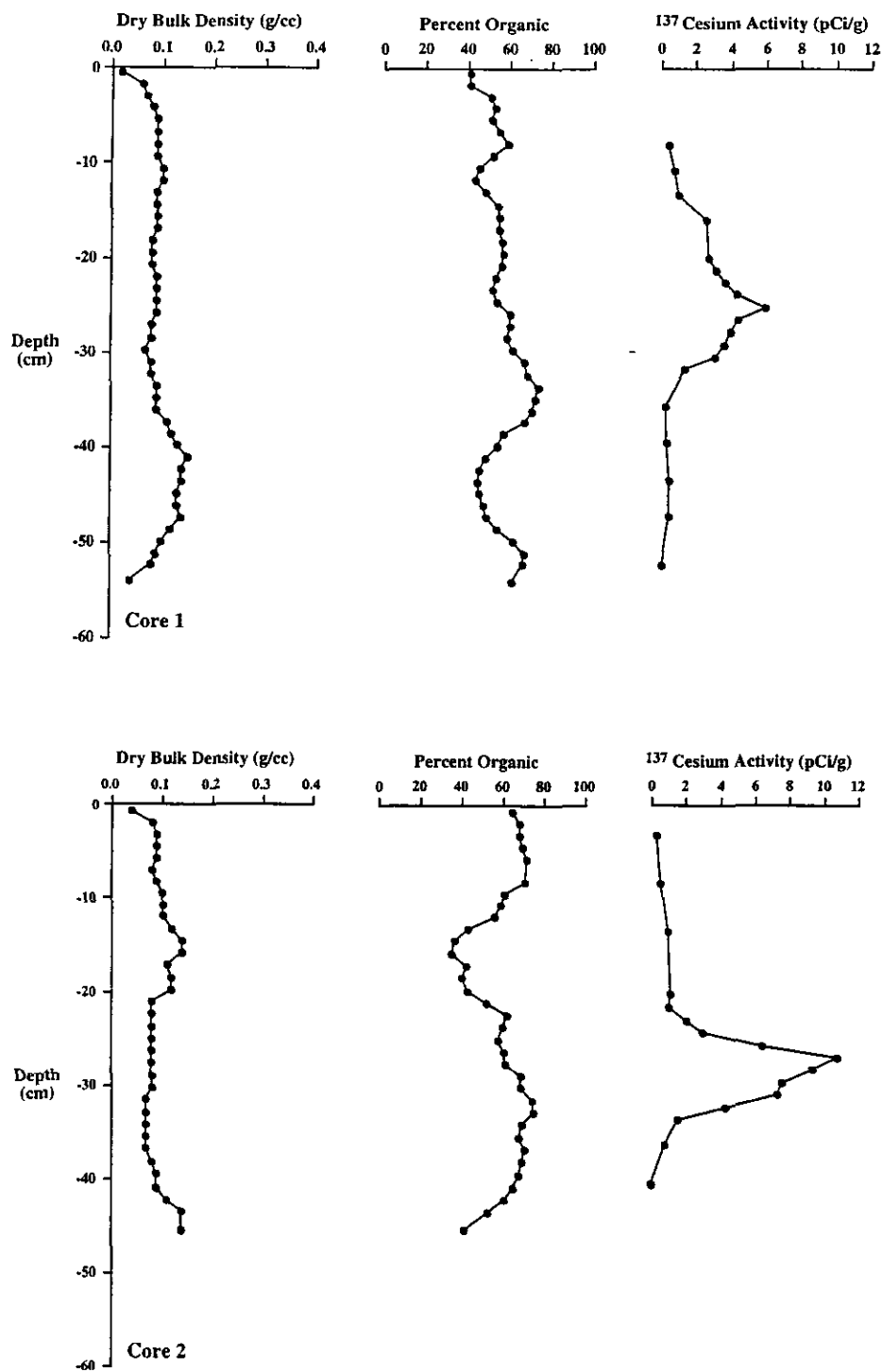


Figure 6.2. <sup>137</sup> Cesium profiles of cores collected from Grand Bayou sites. Core 1 corresponds to site number GB13 (see Figure 6.4); and core 2 corresponds to site GB14 (see Figure 6.4).

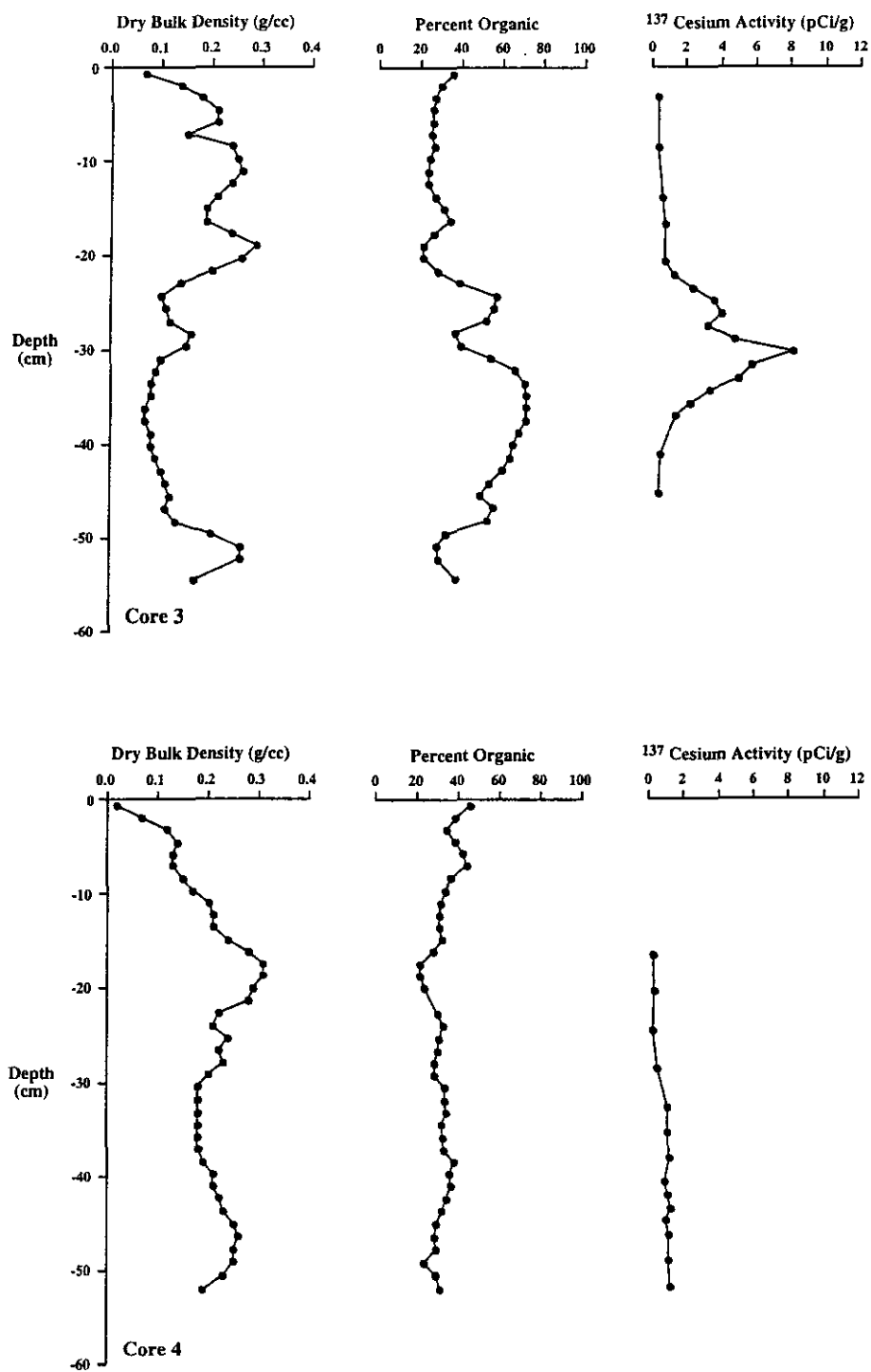


Figure 6.3. <sup>137</sup> Cesium profiles of cores collected from Lake Boudreaux sites. Core 3 corresponds to site number LB8 (see Figure 6.4); and core 4 corresponds to site LB9 (see Figure 6.4).

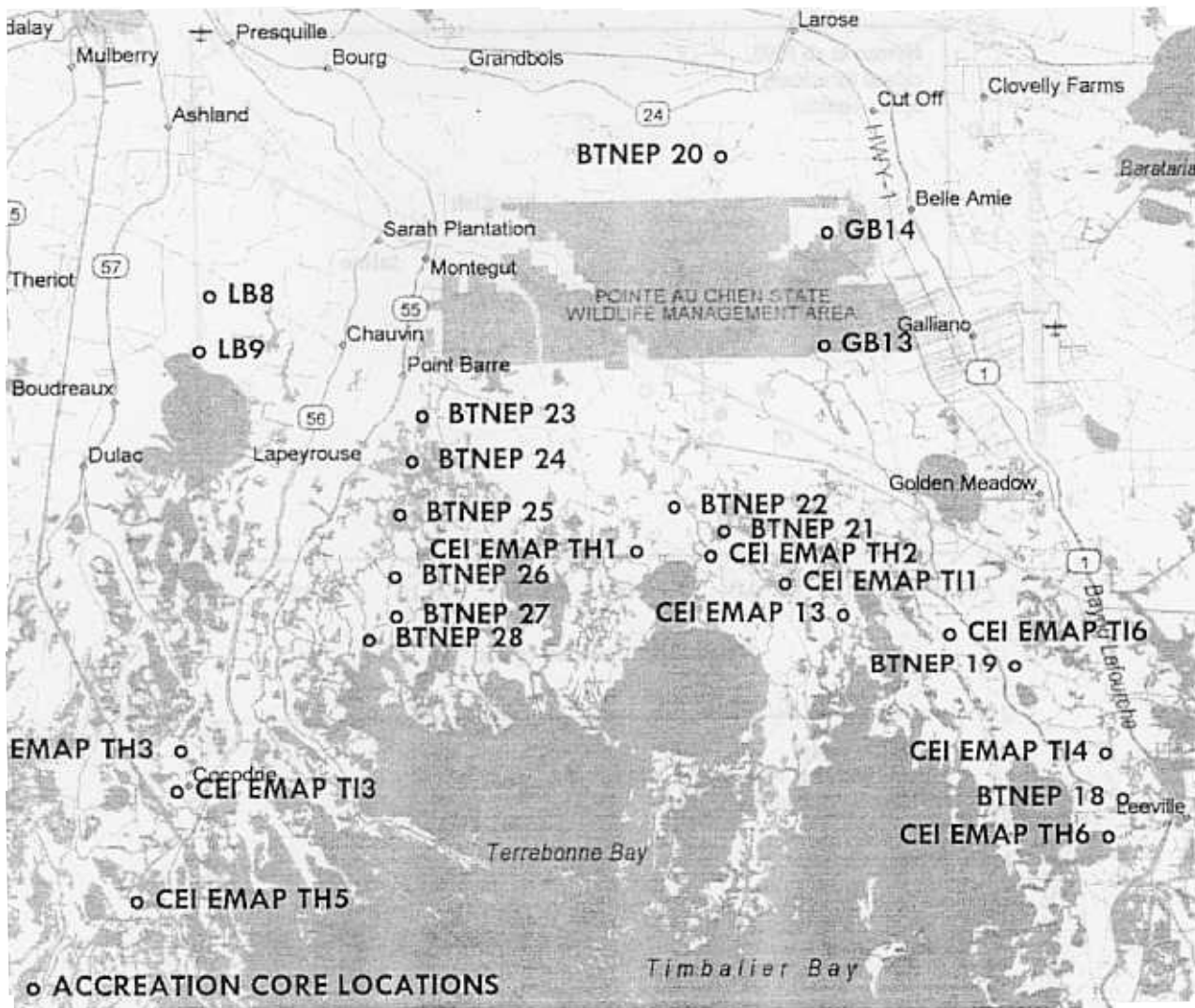


Figure 6.4. Locations of accretion cores collected in other studies (see Table 6.2).

Considering a relative sea level rise rate (including subsidence) of  $1.12 \text{ cm yr}^{-1}$  (see hydrology section in this report), accretion rates in the Grand Bayou study area are too low to compensate for submergence. Only the Lake Boudreaux site has accretion an adjusted accretion rate (unadjusted rate =  $0.80 \text{ cm yr}^{-1}$ ; then add  $0.18 \text{ cm yr}^{-1}$  to compensate for tussock height; this yields a total of  $0.98 \text{ cm yr}^{-1}$ ) that may cope with submergence. How representative the Boudreaux core is with respect to the larger basin is unknown. Table 6.2 and Figure 6.5 contain estimates of vertical accretion from other studies conducted in Terrebonne basin brackish and saline marshes.

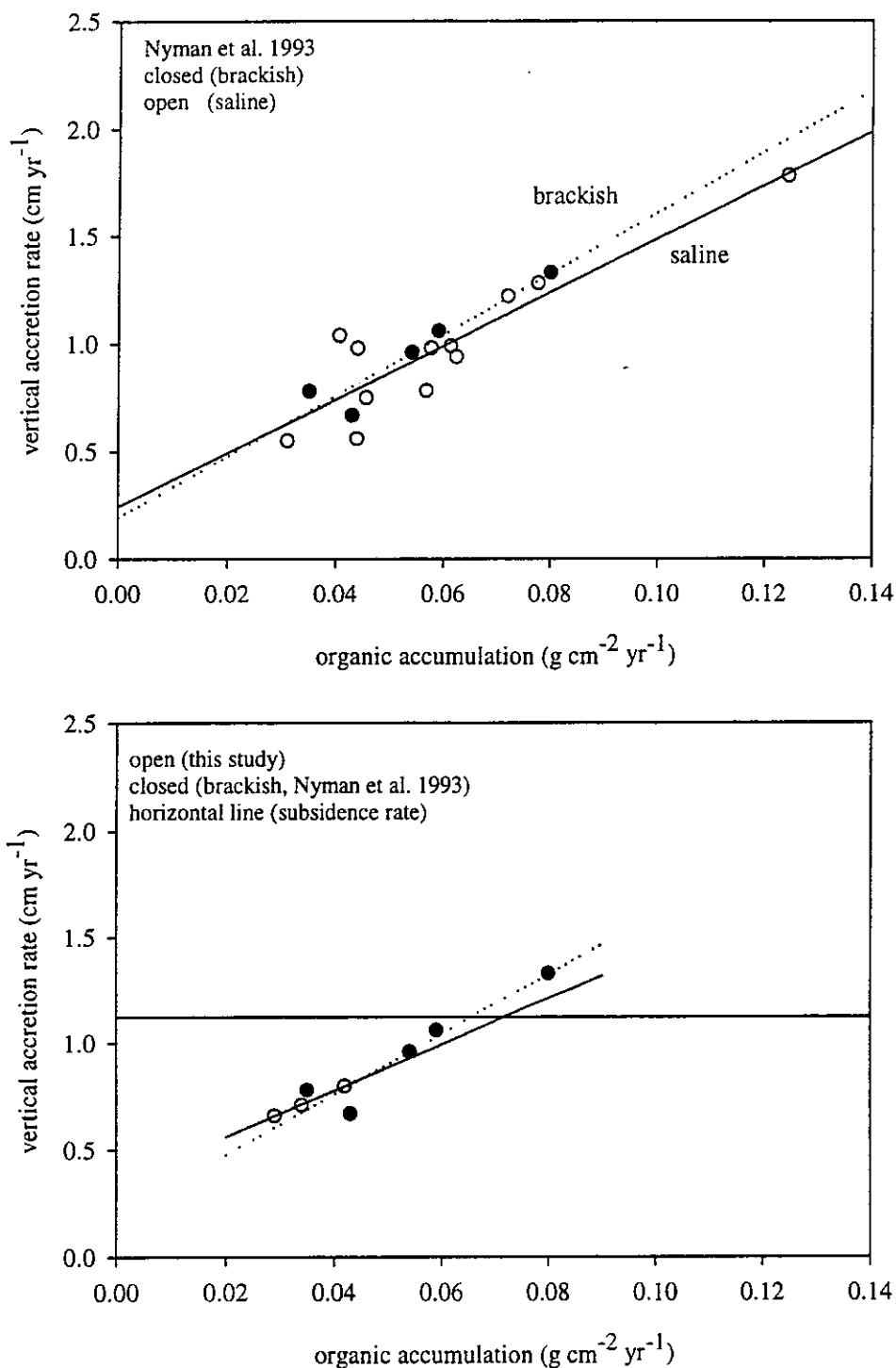


Figure 6.5. Vertical accretion rates associated with Terrebonne basin (Louisiana) saline and brackish marshes (top, Nyman et al. 1993) and results from this study (bottom, open circles) compared to brackish marshes. A cumulative sea level rise plus subsidence rate is approximated at 1.1 cm yr<sup>-1</sup> (see hydrology section of this report).

Table 6.2. Summary of accretion rates for marsh types within the study areas (after Kesel and Reed 1995).

Site Number	Site Description	Reference	Accretion cm yr-1	Notes
BTNEP 18	Golden Meadow Field	DeLaune et al., 1992	0.70	
BTNEP 19	Grand bayou Blue	Pardue et al, 1988	0.86	
BTNEP 19	Grand Bayou Blue	Delaune et al, 1992	0.86	
BTNEP 20	Bayou Blue	Cahoon, et al.	0.41	pre-Andrew
BTNEP 20	Bayou Blue	Cahoon et al.	7.08	post-Andrew
BTNEP 21	Lower Pointe au Chien	Reed, 1992	4.20	streamside, control
BTNEP 21	Lower Pointe au Chien	Reed, 1992	3.30	backmarsh, control
BTNEP 22	Bayou Jean La Croix	Reed, 1992	1.8	control site
BTNEP 23	Montegut marsh	Reed, 1992	4.20	backmarsh control
BTNEP 26	Bayou Barre	Nyman et al., 1993	0.96	brackish marsh
BTNEP 27	Bayou Barre	Nyman et al., 1993	0.99	saline marsh
BTNEP 28	Bayou Chitigue	DeLaune, et al, 1992	1.02	
EMAP TH1	N. Lake Felicity	Turner and Swenson, 1994	0.77	saline marsh
EMAP TH2A	Lake Billiot	Turner and Swenson, 1994	0.81	saline marsh
EMAP TH2B	Lake Billiot	Turner and Swenson, 1994	0.89	saline marsh
EMAP TH2C	Lake Billiot	Turner and Swenson, 1994	0.63	saline marsh
EMAP TI1	Bayou Pierre et Lee	Turner and Swenson, 1994	0.68	saline marsh
EMAP TH6	Hackberry Bay	Turner and Swenson, 1994	0.79	saline marsh
GB13	Grand Bayou	This study	0.66	
GB14	Grand Bayou	This study	0.71	
LB8	Lake Boudreaux	This study	0.80	brackish

## **CHAPTER 7: SUMMARY AND CONCLUSIONS**

### **Historical Habitat Conditions**

The area of marsh within the Lake Boudreaux and Grand Bayou study areas has changed significantly over the past 50 years (Figure 2.16). In the Lake Boudreaux study area, total marsh area decreased from 20,894 acres in 1956 to 11,420 acres in 1998, a loss of about 45% of marsh acres over the period. The marsh area in the Grand Bayou study area decreased from 49,286 in 1956 to 31,504 in 1998, a loss of about 36% of marsh acres. Most of the marsh loss occurred between 1956 and 1988 in both study areas, with marsh area fairly stable between 1988 and 1998.

The marsh systems in both Lake Boudreaux and Grand Bayou study areas were much fresher in the 1950's compared to the present, as reflected in vegetation community changes over the period. O'Neil designated marshes in the upper regions of both study areas on his 1949 vegetation community map as fresh maidencane marsh types. He mapped marshes in the lower portions of both study areas as "floating 3-corner grass" marsh, reflecting the influence of low salinity water in this region. Since the 1950's, the vegetation in both study areas has reflected a shift to more salt tolerant vegetation species. Data from our 1998 photo-interpretation study indicate the freshwater marsh covered approximately 14% of both study areas. The largest marsh type in the Grand Bayou study area was mesohaline (brackish), covering about 60% of the total marsh. The oligohaline (intermediate) marsh covered 24% of total marsh area and polyhaline (salt) covered about 1%. In the Lake Boudreaux study area the mesohaline marsh was also the largest vegetation type, covering about 47% of the total marsh area. The oligohaline marsh covered about 36% and the polyhaline marsh accounted for about 3%.

### **Marsh Degradation**

The area of water within the Lake Boudreaux and Grand Bayou study areas has also changed significantly over the past 50 years. In the Lake Boudreaux study area, total water area increased from 674 acres in 1956, 4,861 acres in 1978, 8,884 acres in 1989 and 11,420 acres in 1998. The Grand Bayou study area water class increased from 2,757 acres in 1956, to 12,267 acres in 1978, 21,504 acres in 1988, and remained about the same at 21,190 acres in 1998.

Using the 1998 aerial photography, the percentage of water in the marsh and configuration of marsh water bodies were determined, categorized, and used as indicators of marsh degradation in this study to evaluate marsh condition. Classes 1 through 6 represented differing amounts of water within the marsh (Table 2.3). Categories a,b,c, represented different water body configurations within the marsh (Table 2.3). It is clear from the increased open water in both study areas that the marshes in both study areas have degraded since 1956 (Figure 2.17). However both degradation indicators suggest that the Grand Bayou study area has less degraded marshes, particularly in the fresh and low salinity marshes, than the Lake Boudreaux study area. In the Lake Boudreaux study area the largest percentage of each of the marsh types represented were in classes 4 and 5 (Figure 2.6). Conversely, in the fresh and low salinity marshes in the Grand Bayou study area the marsh types were in less degraded categories, with more marsh in class 3. The difference in the fresh and low salinity marshes between these two study areas is especially noteworthy, since the fresh water for restoration would likely be introduced into these parts of the study areas.

A higher percentage of marsh area was designated category “c” in the Lake Boudreaux study area than in the Grand Bayou study area marshes (Figure 2.8). This category represents the most degraded category, indicating more large and small open water areas within a matrix of marginal marsh.

### **Vegetation**

Vegetation species composition and cover value data collected at 14 sites in the Lake Boudreaux study area facilitated classification into 6 vegetation types (Fresh Maidencane, Fresh Bulltongue, Oligohaline Bulltongue, Oligohaline Paspalum transition, Oligohaline Wiregrass, and Mesohaline Wiregrass). The Mesohaline Wiregrass type was present at the most sites (6). The vegetation at 17 sites in the Grand Bayou study area was classified into 7 types including Fresh Maidencane, Fresh Spikerush, Fresh Bulltongue, Oligohaline Paspalum transition, Oligohaline Wiregrass, Mesohaline Wiregrass, and Mesohaline Mixture. The most common vegetation types in this study area were Mesohaline Wiregrass and Mesohaline Mixture, with 5 sites each.

Total cover and species richness were generally lower in the Lake Boudreaux study area compared to the Grand Bayou study area. The Fresh Maidencane marshes, in the upper parts of both study areas, had lower species richness than the “healthy” Fresh Maidencane marshes, but were within the range of FM marshes. However the relative dominance of *Panicum hemitomon*, the dominant plant in this type, is lower in the studied sites than the relative dominance of this species in “healthy” Fresh Maidencane marshes.

Several observations on field visits to both Lake Boudreaux and Grand Bayou study areas are noteworthy. In both regions significant areas of bulltongue “transition” marshes dominated by *Acnida* sp. and *Paspalum* sp. were present. The presence of these opportunistic vegetation species indicate a species shift (from *Sagittaria falcata*-dominated assemblage) in response to disturbance, probably due to gradually increasing water salinity over the long-term, accelerated by the drought conditions of the last two years. Likewise, the common occurrence of the fern *Thelypteris palustris* in the Fresh Maidencane marsh in the Grand Bayou study area and its absence in the Lake Boudreaux study area is significant, because we generally associate this species with “healthy” Fresh Maidencane marshes.

### **Soil Bulk Properties**

Average bulk density, root mat thickness, and soil strength were similar between the Lake Boudreaux and Grand Bayou study areas. With respect to bulk density, the substrate data from these study areas is within the range of values reported by Sasser et al. (1994) for freshwater and oligohaline marshes in the Barataria/Terrebonne basins. With depth in the soil profile, the soil strength varied little among study areas except the upper 5 cm of the soil profile in the Grand Bayou marshes exhibited greater strength compared to Lake Boudreaux marshes. However, the strength in the upper 15 cm (the live root zone) of both study areas was significantly less than that of McGinnis (1997), who measured the strength of soils associated with vegetated *Spartina patens* hummocks.

### **Sediment Accretion**

Three of the four cores extracted in this study (two in each study area) were useful for conducting accretion analysis; one core did not exhibit a discernable peak in cesium activity. Therefore our analysis comprised two cores from Grand Bayou study area and one core from

Lake Boudreaux study area. The core from the Lake Boudreaux area had the highest accretion rate (0.80 cm yr<sup>-1</sup>) compared to the two sites at Grand Bayou, which had accretion rates of 0.66 and 0.71 cm yr<sup>-1</sup>. The Lake Boudreaux area core was located streamside to Bayou Chauvin in marshes near the northern edge of the lake, which may explain its relatively high rate of accretion compared to the Grand Bayou sites. Mineral accumulation at the Lake Boudreaux site is 3 times higher than Grand Bayou sites, thus it is likely that mineral sediments that are resuspended from the lake bottom with storm tides are transported readily to the location of the core in the streamside marsh adjacent to Bayou Chauvin north of Lake Boudreaux.

In general, the accretion rates from this study are within the lower range of other brackish marshes in Terrebonne basin. Grand Bayou sites had both organic and mineral accumulation rates that were lower than reported values. Organic matter accumulation is the dominant form of accretion in the Grand Bayou study area cores, whereas the Lake Boudreaux marsh soil profile indicated appreciably more mineral sediment. Considering a relative sea level rise rate of 1.12 cm yr<sup>-1</sup> (see Hydrology section below), accretion rates in the Grand Bayou study area are too low to compensate for submergence. The accretion rate at the single Lake Boudreaux site near the lake was high enough to compensate for submergence, however this site may not be representative with respect to the study area.

## **Hydrologic Characteristics**

### **Water**

Analysis of water level data from area data collection stations (Grand Isle, Leeville, Catfish Lake, and Houma) indicate relative sea level rise in the area ranges from 0.77 to 1.49 cm yr<sup>-1</sup>, averaging 1.11 cm yr<sup>-1</sup>. The total water level fluctuations observed are about 3.3 feet, with the tidal forcing equal to about 1.0 feet. Both study areas show a decrease in tidal amplitudes from 1 foot at the southern end to 0.1 foot at the northern end of the study areas. The canal network in the west side of the Grand Bayou study area has a much higher tidal amplitude than would be expected, based on distance inland. This is most likely due to the canals providing a pathway into the study area.

## **Salinity**

Analysis of salinity data from the area indicate that salinities in the southern portion of the study areas are typically around 10-12 ppt, although values of 20-30 ppt have been observed. Data from Bayou Lafourche (at Leeville) and Petite Caillou (at Cocodrie) show greatly reduced salinities due to the freshwater in these bayous.

## **Water Budget**

Precipitation water budget calculations indicates a mean surplus of 128.7 cfs for the Grand Bayou study area and 59.7 cfs for the Lake Boudreaux study area. If these surpluses are adjusted for areas (and freshwater sources) not accounted for in the project area the values are about 171 cfs for the Grand Bayou study area and about 119 cfs for the Lake Boudreaux study area.

The calculated freshwater renewal times are 65 to 157 days for the Lake Boudreaux study area and 60 to 182 days for the Grand Bayou study area. The range in values results from the uncertainty in the surplus estimate from areas outside the project area. The calculated renewal time for tidal prism exchange is 8.6 days for the Lake Boudreaux study area and 7.5 days for the Grand Bayou study area. These numbers represent the renewal times that would occur with complete mixing on each tidal cycle.

## **Significance for Restoration Strategy**

Overall, the marsh systems in both Lake Boudreaux Basin and the Grand Bayou Basin are in significantly degraded condition and would likely benefit from fresh water and sediment introduction. Based on the results of data collected in this study, a review of data from the literature, and our observations in the field, the marshes in the Lake Boudreaux Basin seem to be somewhat more degraded than those in the Grand Bayou marshes. More of the fresh and oligohaline marshes in particular are in better condition in the Grand Bayou area, while the mesohaline marshes in both study areas are in relatively poor condition.

A salt gradient influences both study areas, but may be sharper in the Grand Bayou area. The estimates of the water budget and flux indicate that precipitation is minor compared to the tidal flux, but that the proposed freshwater diversion of 2000-4000 cfs is about equal to the tidal flux. Potential for freshening the system is very good.

## **Development of a Restoration Strategy**

### **(Comparison of Present Ecological Conditions to “Ideal” Marsh Conditions)**

In addition to evaluating present and historic ecological conditions in the two study areas, our approach to developing information for determining a study area restoration strategy includes providing information that facilitates a quantitative comparison of important ecological variables describing the present marsh condition to “ideal marsh” conditions. By comparing the condition of an existing marsh in terms of the important “drivers” that influence emergent vegetation growth and marsh substrate sustainability to conditions in an “ideal” marsh, we can determine the appropriate variables that must be influenced in order to force a positive habitat change in the marsh system.

The successful restoration of a habitat can best be accomplished when the critical environmental conditions (variables) of the desired habitat type are clearly quantified. This set of criteria then becomes the target toward which restoration points. Planning for restoration requires not only the characterization of the habitat type but also quantification of the same variables in the area to be restored, that is, the existing habitat. Restoration, in this context, is the trajectory of change of the critical environmental variables from the existing set to the target set. In this proposed CWPPRA project, the restoration trajectory is to be manipulated by changing the freshwater input.

Since an environment can be characterized by any number of environmental variables, we use the term “critical” variables to indicate those that clearly and quantitatively determine, at least to some measurable extent, what determines the emergence of a specific habitat type. For example, in a marsh environment water salinity is a major determinant of the vegetation that grows on the marsh (Chabreck, 1970; Brupbacher, 1973). The stability of the marsh, given a certain salinity range, is related to the vertical accretion rate of the marsh surface relative to local apparent sea level rise (DeLaune, 1983; DeLaune, 1990; Nyman, 1993), and may be governed by the flux of mineral sediment. The “target” habitat is a “virtual” marsh, resulting from careful examination of available literature to determine and quantify critical variables. The data in Table 7.1 are a “first attempt” to quantify the critical variables for each of the marsh vegetation types, with data obtained for “healthy” marshes from the literature.

Table 7.1 Data ranges for several critical variables in "healthy" marshes based on literature review and Coastal Ecology Institute datasets.

Category	Variable	Fresh Maidencane	Fresh Spikerush	Fresh Bulltongue	Oligohaline Bulltongue
Hydrology	Frequency of flooding <sup>i</sup>	0	1-5	12-30	20-50
	Duration of flooding <sup>ii</sup>	0	50	75	50
	Flux index <sup>iii</sup>	> 780	> 780	> 780	> 1800
	Connectivity index <sup>iv</sup>	> 0.9	> 0.9	> 0.9	> 0.9
Surface Water	Salinity <sup>v</sup>	< 2 ppt	< 2 ppt	< 2 ppt	2-5 ppt
	Suspended Sediments				
	Nitrogen (TKN) Phosphorus (TP)				
Substrate	Accretion	0.75 cm/yr			
	Bulk density	< 0.05 g/cm <sup>3</sup>	< 0.05 g/cm <sup>3</sup>	0.05-0.09 g/cm <sup>3</sup>	0.05-0.09 g/cm <sup>3</sup>
	Mat thickness	> 35 cm	> 15 cm	> 20 cm	> 20 cm
	Mat strength <sup>vi</sup>	> 0.4 kg/cm <sup>2</sup>	> 0.4 kg/cm <sup>2</sup>	> 0.4 kg/cm <sup>2</sup>	> 0.4 kg/cm <sup>2</sup>
	Mat buoyancy				
Landscape	Degradation index				
Vegetation	Dominance <sup>vii</sup>	<i>Panicum hemitomon</i> > 70	<i>Eleocharis baldwinii</i> > 10	<i>Sagittaria lancifolia</i> > 10 <i>Panicum hemitomon</i> < 50	<i>Sagittaria lancifolia</i> > 20 <i>Eleocharis</i> spp. > 20
	Diversity	> 8 species/m <sup>2</sup>	> 5 species/m <sup>2</sup>	> 5 species/m <sup>2</sup>	> 8 species/m <sup>2</sup>
	Aboveground biomass	> 800 g/m <sup>2</sup>	> 300 g/m <sup>2</sup>	> 500 g/m <sup>2</sup>	> 300 g/m <sup>2</sup>
	Belowground biomass	> 900 g/m <sup>2</sup>	> 100 g/m <sup>2</sup>	> 600 g/m <sup>2</sup>	?

(continued)

Table 7.1 Continued.

Category	Variable	Oligohaline Wiregrass	Mesohaline Wiregrass	Mesohaline Mixture	Polyhaline Oystergrass
Hydrology	Frequency of flooding	20-50	60-180	60-180	300-365
	Duration of flooding	50	60	60	75
	Flux index	> 1900	> 11000	> 11000	> 49500
	Connectivity index	> 0.9	> 0.9	> 0.9	> 0.9
Surface Water	Salinity	2-5 ppt	5-18 ppt	5-18 ppt	18-30 ppt
	Suspended Sediments				
	Nitrogen (TKN)				
	Phosphorus (TP)				
Substrate	Accretion		0.96 cm/yr		
	Bulk density	> 0.09 g/cm <sup>3</sup>	> 0.09 g/cm <sup>3</sup>	> 0.09 g/cm <sup>3</sup>	> 0.20 g/cm <sup>3</sup>
	Mat thickness	> 20 cm	> 20 cm	?	?
	Mat strength	> 0.4 kg/cm <sup>2</sup>	> 0.4 kg/cm <sup>2</sup>	?	?
	Mat buoyancy				
Landscape	Degradation index				
Vegetation	Dominance	<i>Spartina patens</i> >25	<i>Spartina patens</i> >75	<i>Spartina alterniflora</i> <50 <i>Distichlis spicata</i> >10	<i>Spartina alterniflora</i> >90
	Diversity	> 7 species/m <sup>2</sup>	1-2 species/m <sup>2</sup>	2-3 species/m <sup>2</sup>	1 species/m <sup>2</sup>
	Aboveground biomass	> 800 g/m <sup>2</sup>	> 800 g/m <sup>2</sup>	> 800 g/m <sup>2</sup>	> 300 g/m <sup>2</sup>
	Belowground biomass	> 600 g/m <sup>2</sup>	?	?	> 150 g/m <sup>2</sup>

<sup>i</sup> Number of flooding events<sup>ii</sup> Percentage of the year flooded<sup>iii</sup> Frequency of flooding events x amplitude of water level<sup>iv</sup> Slope between marsh water level and open water level, removing data with water levels below marsh level.<sup>v</sup> Mean annual<sup>vi</sup> Torvane<sup>vii</sup> Relative Dominance (fall) = the cover of the species of interest divided by the sum of the cover of all species.

Table 7.2 shows the data available from the Lake Boudreaux and Grand Bayou study areas with a comparison to "ideal" marsh conditions. Although bulk density of the substrates is in the range observed in "healthy" marshes, accretion is below these values. Marsh mat thickness and strength, which could be indicators of belowground biomass, show that these are below values measured in "healthy" marshes as well. Little difference in these substrate characteristics were observed between the two study areas. Vegetation diversity and cover were below values measured in "healthy" marshes and on average, the Lake Boudreaux study area had lower diversity and cover than the Grand Bayou study area.

Our evaluation of the Lake Boudreaux and Grand Bayou study areas indicate marshes in both are degraded and would benefit from restoration activities, however marshes in the Lake Boudreaux study area are more degraded than those in the Grand Bayou study area. The addition of freshwater into either of these marsh systems should dramatically improve the productivity of emergent vegetation in the fresh and oligohaline marshes, and may have smaller positive effects in the mesohaline and polyhaline marshes. The increased biomass production of above and belowground plant material would have a positive effect on accretion and vegetation cover. Any increased sediment supply associated with the additional freshwater would provide further positive influence on accretion rates as well as plant productivity. Our evaluation of marsh conditions in the two study areas indicated the mesohaline marshes in the lower study areas are highly degraded. If possible, freshwater and sediment addition directly into the lower portion of the study areas could significantly enhance emergent marsh productivity, increase accretion rate, and overall significantly improve the condition of more saline marsh types.

Table 7.2. Comparison of study area marshes with "healthy" marsh.

Category	Variable	Oligohaline Marsh			Mesohaline Marsh		
		Virtual	LB	GB	Virtual	LB	GB
Hydrology	Frequency of flooding	20-50			60-180		
	Duration of flooding	50			60		
	Flux index	> 1800			> 11000		
	Connectivity index	> 0.9			> 0.9		
Surface Water	Salinity	2-5			5-18		
Substrate	Accretion				0.96	0.80	0.66-0.71
	Bulk density		<0.08	<0.08	> 0.09	>0.12	>0.12
	Mat thickness	0.05-0.09	<20	<20	> 20	<20	<20
	Mat strength	> 0.4	<0.2	<0.2	> 0.4	<0.2	<0.2
Vegetation	Dominance	<i>S.lan</i> >20 & <i>E.spp</i> >20 or <i>S.pat</i> >25	<i>S.lan</i> =7 & <i>E.spp</i> =4 or <i>S.pat</i> =92	<i>S.lan</i> =0 & <i>E.spp</i> =0 or <i>S.pat</i> =79	<i>Sp.pat</i> >75 or <i>Sp.alt</i> <50 & <i>D.spi</i> >10	<i>Sp.pat</i> =87	<i>Sp.pat</i> =87 or <i>Sp.alt</i> =6 & <i>D.spi</i> =58
	Diversity	> 8	1-8	2-5	1-2	1-3	2-4
	Above-ground biomass (estimated with cover)	≥ 100	60-100	40-107	≥ 100	35-100	95-120

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